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THE ITER PROJECT

CONSTRUCTION, MANUFACTURING & ASSEMBLY

PROGRESS IN PICTURES

2013 2024

JAPAN EDITION 日本版

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CAPTURING THE FIRE OF THE STARS

—

In the early decades of the 20th century physicists began to understand the processes at work in the core of the Sun and Sun-like stars. There, under tremendous pressure and extreme temperature, complex nuclear reactions continuously fuse hydrogen into helium, generating colossal amounts of energy.

As soon as the "fusion reaction" was identified, the scientific community worldwide formed the ambition to reproduce it and tap its formidable energy potential.

International research and technology have progressed at a fast pace over the past 70 years. Fusion research has now reached the point where the feasibility of this new energy source can be demonstrated. This is the mission of ITER, an unprecedented international collaboration that brings together China, the European Union, India, Japan, Korea, Russia and the United States.

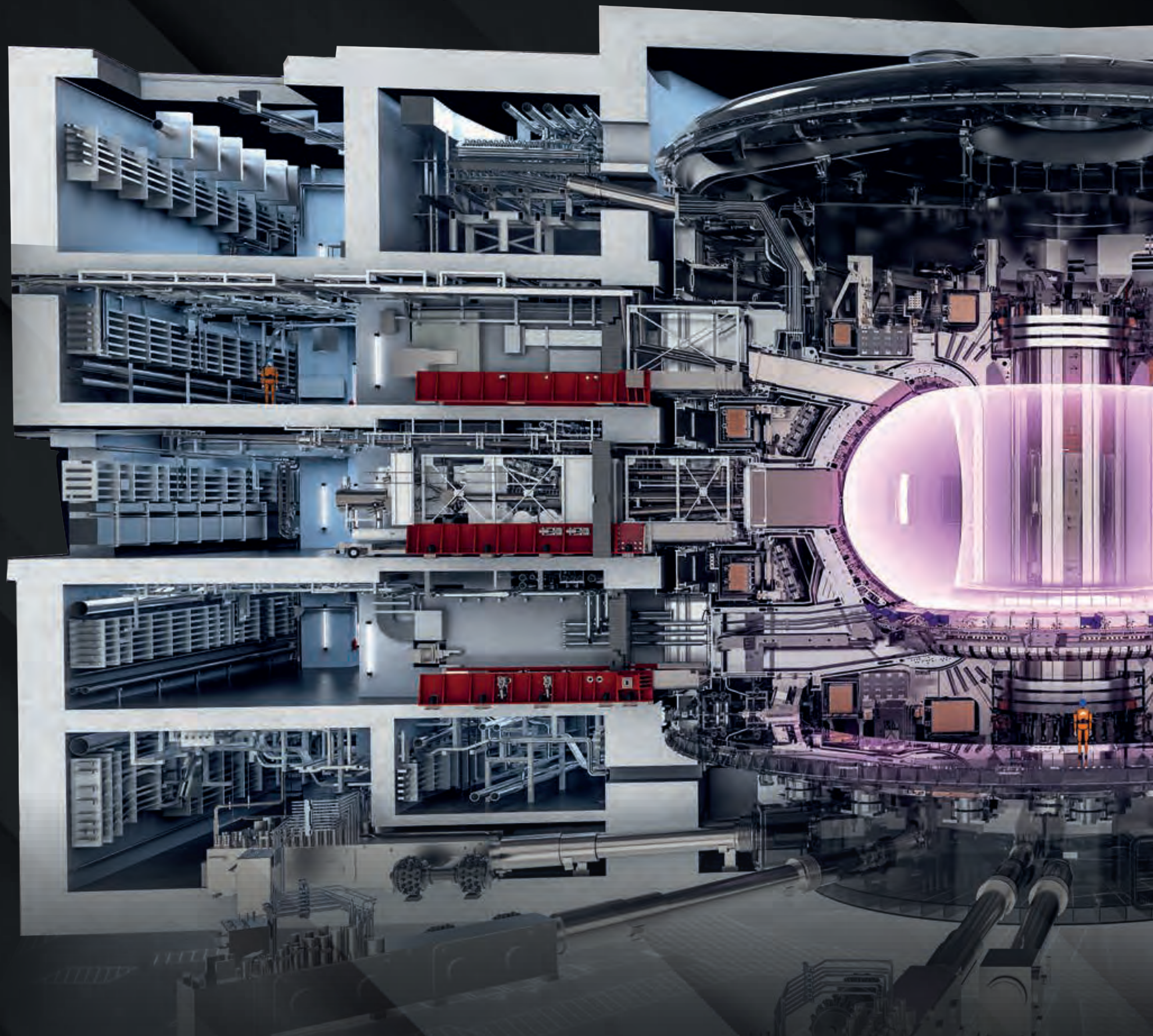
The ITER scientific installation is located in southern France. Seven ITER Members, representing half the world's population, share the responsibility for building the ITER machine—a tokamak[1]— and facilities.

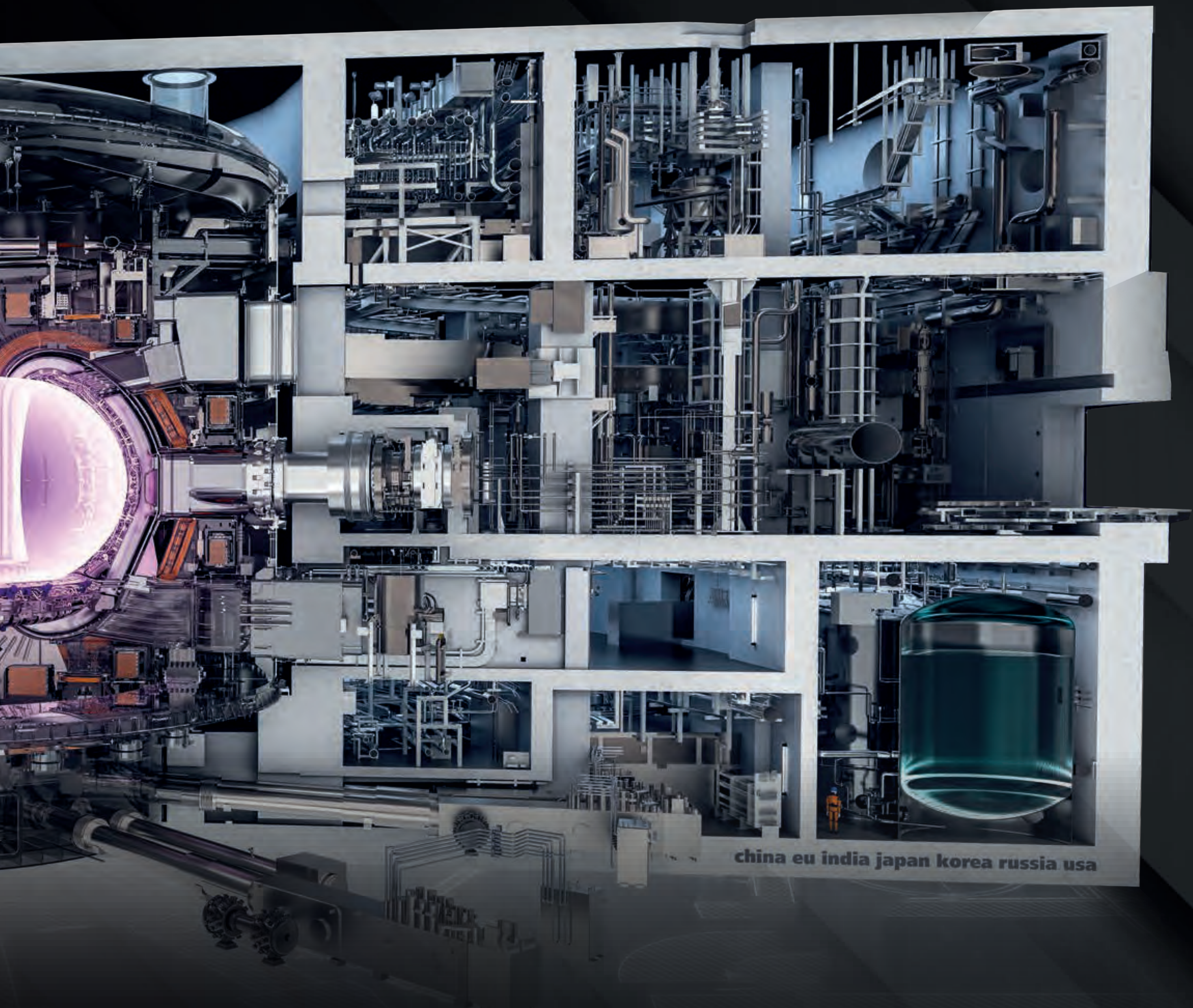
Procuring components and systems, each Member benefits by direct industrial experience in key fusion technologies and also shares in intellectual property generated by others.

As building on the construction platform comes to an end and some of the longest-lead procurement programs conclude, ITER has fully entered the machine assembly phase.

This book of photographs aims to take you into the heart of the ITER project – from the rolling hills of Provence to factories on three continents where men and women from 33 nations are bent on realizing one of humankind's most enduring dreams: capturing the fire of the stars and making it available to the generations to come.

[1] "tokamak" is a Russian acronym meaning "toroidal chamber – magnetic coils"





THE ITER TOKAMAK

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Tokamaks were developed in the 1960s at a time when the international fusion community was experimenting with different machine concepts aiming at reproducing the nuclear reactions at work in the core of the Sun and Sun-like stars.

The tokamak design soon proved particularly efficient and in the following decades more than two hundred tokamaks entered operation around the world. Exploring plasma physics and experimenting with materials and technologies, they paved the way for ITER.

ITER is by far the largest and most powerful tokamak ever built, and the first to integrate the components and systems required by future industrial and commercial fusion plants.

With five times the plasma volume of the largest machine operating today, the ITER tokamak will be a unique experimental tool and the first to reach the state of a burning plasma, when the heat from the fusion reaction is confined within the plasma efficiently enough to maintain the temperature of the plasma.

A burning plasma in which at least 50 percent of the energy to drive the fusion reaction is generated internally is an essential step to reaching the goal of fusion power generation.

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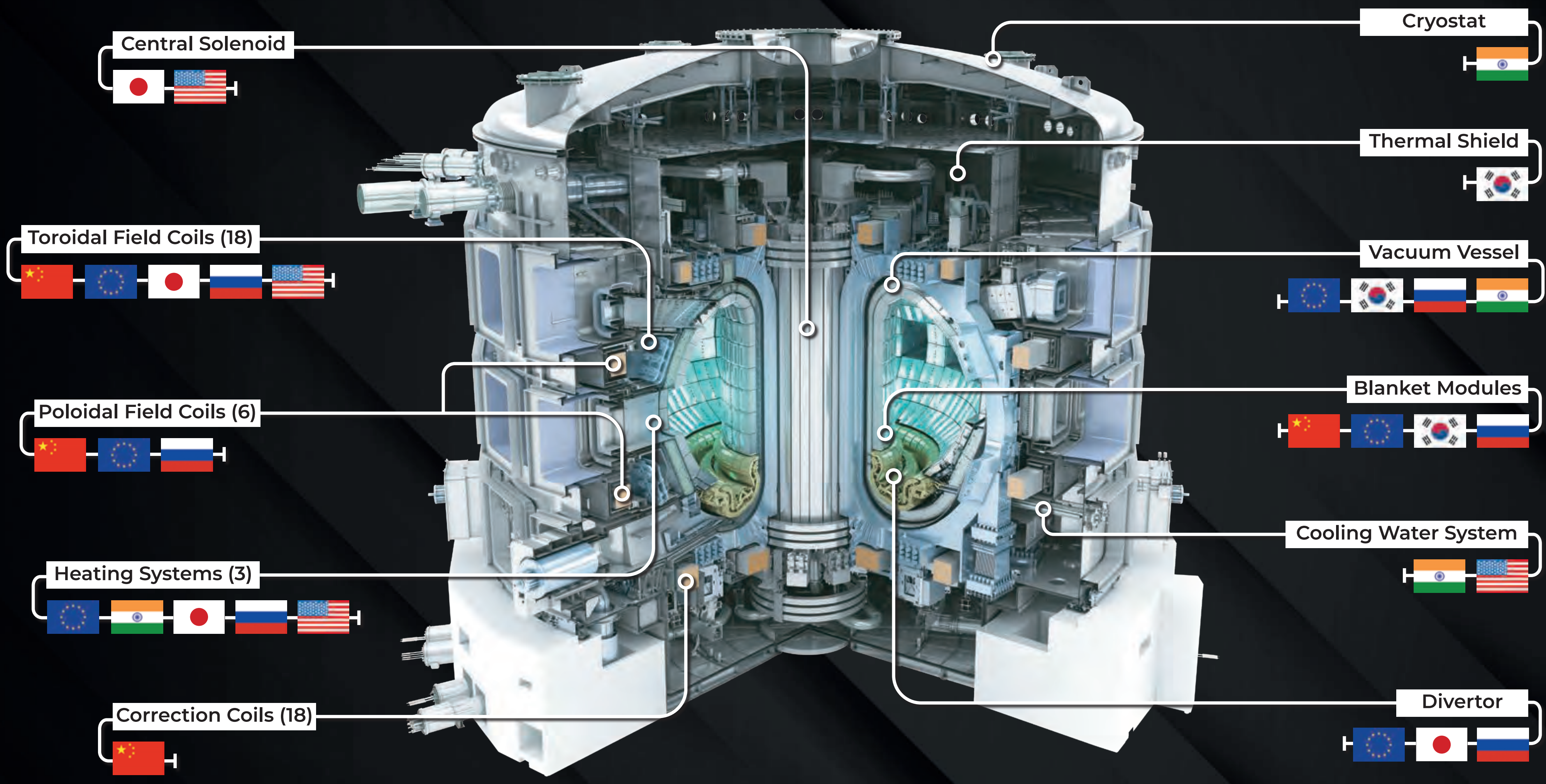
WHO MANUFACTURES WHAT?



On 28 June 2005, the seven ITER Members unanimously agree on the site proposed by Europe: a 180-hectare stretch of land located in the Durance River Valley some 75 kilometres north of Marseille, France. Preparation work on the ITER site begins in January 2007. Over two years a platform is cleared, levelled and readied for building construction, which begins in the summer of 2010.

A few members of the "Unique ITER Team" in 2013. Osamu Motojima, the project's second Director-General, speaks with Domestic Agency heads Kijung Jung (Korea), Jean-Marc Filhol (Europe, acting), Eisuke Tada (Japan), and Ned Sauthoff (United States).

Contractors are preparing to pour 15,000 m³ of concrete for the "floor" of the Tokamak Complex—the 1.5-metre-thick B2 slab. With rebar, the B2 slab weighs 37,500 tonnes, a load that is supported by 493 seismic pillars.

Inside Europe's on-site Poloidal Field Coils Winding Facility, a large sun-like spreader beam has been installed for the delicate transport of double pancake windings from station to station.

A partial view of the ITER platform in September 2013. The Poloidal Field Coils Winding Facility (bottom left) has been finalized; work is progressing on the Cryostat Workshop (foreground) and the Assembly Hall/Tokamak Complex (centre). Slightly below the level of the platform, ITER Headquarters, in the background, has office space for approximately 500 staff and contractors.

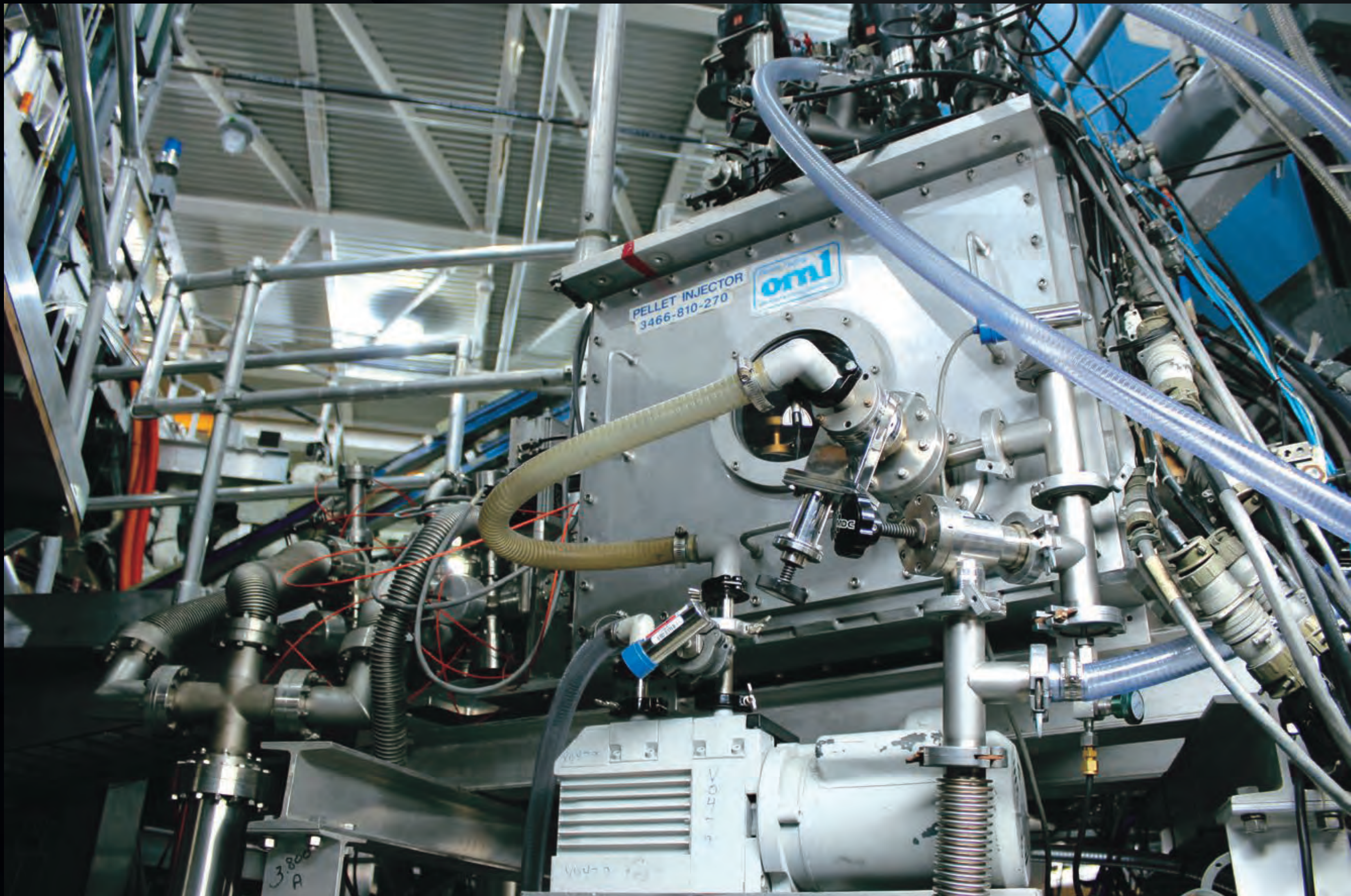
In December 2013, concrete pouring begins for the B2 basemat slab of the 400,000-tonne Tokamak Complex—a suite of buildings that includes the Tokamak Building, the Tritium Building and the Diagnostics Building.

The four-year effort to create the ground support structure and foundations of the Tokamak Complex is brought to a successful conclusion in August 2014, as the last segment of the concrete basemat is poured.

A vacuum vessel prototype, one-third the size of the actual component, undergoes bend testing in Italy. Europe is responsible for five of the nine ITER vacuum vessel sectors.

Vacuum vessel fabrication is also underway in Korea, which is responsible for procuring four of the nine sectors. Pictured: welding operations are carried out at Hyundai Heavy Industries in Ulsan on a small part of one sector.

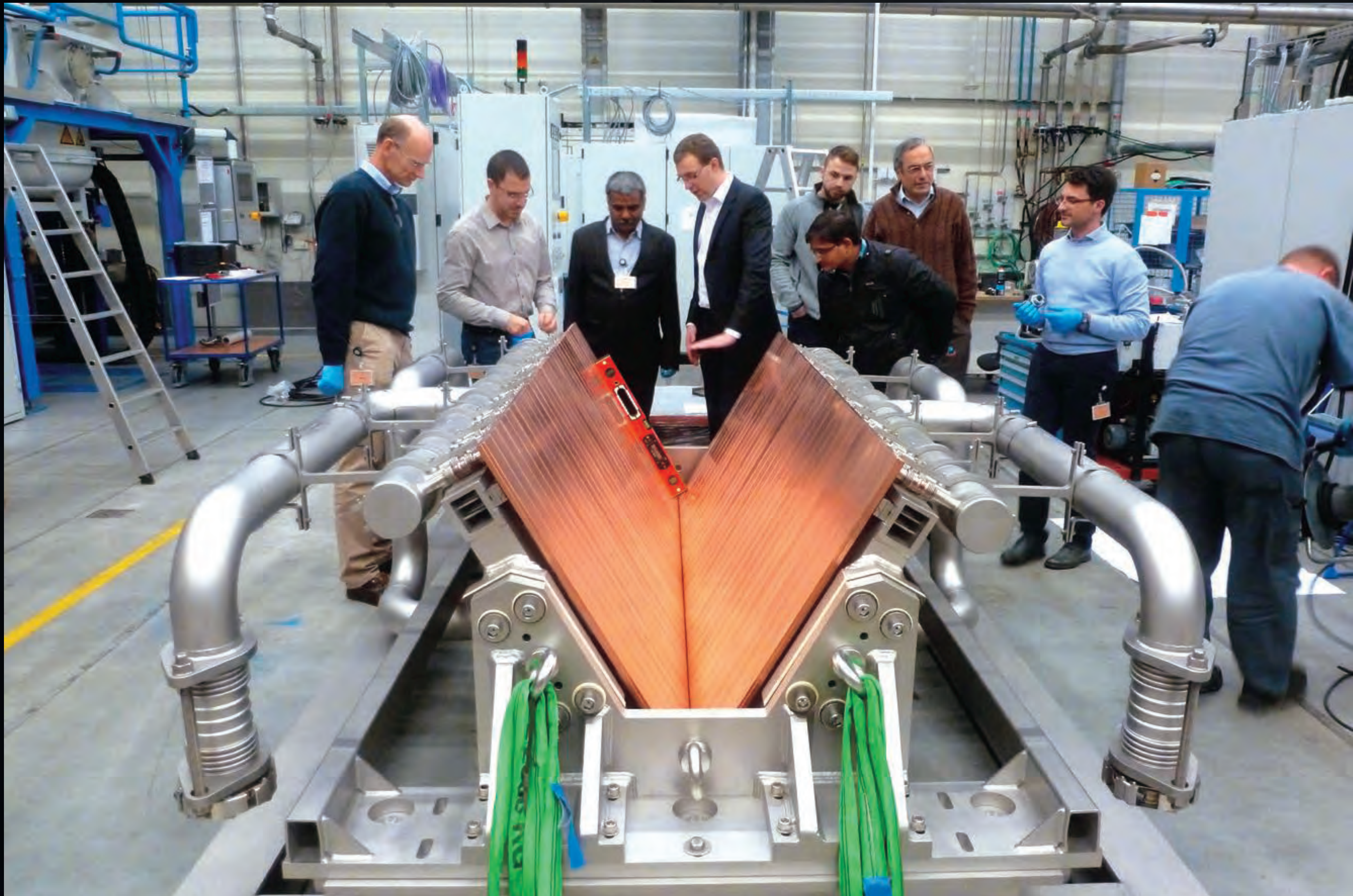
The Chepetsky Mechanical Plant in Glazov, Russia, is producing superconducting strands for ITER's toroidal and poloidal field coils.



The plasma will be fed frozen pellets of fuel, fired into the vacuum vessel by pellet injectors. Here, a pellet injector developed by Oak Ridge National Laboratory is installed on the DIII-D tokamak (San Diego, California) for testing.

In the din and heat of the hot rolling mill at Industeel-Le Creusot, in central France, steel ingots are transformed into plates that will be shipped to industries in Korea, India, Russia and Europe. The plant has already booked some 10,000 tonnes of steel plates for ITER.

The road itinerary between the Mediterranean coast and the ITER site—the "ITER itinerary"—is tested with a 600-tonne load before the arrival of the first ITER components.



In December 2014, India celebrates its first delivery for the ITER Project—a beam dump for the full-scale ion source test bed at the ITER Neutral Beam Test Facility in Padua, Italy.

A 90-tonne electrical transformer procured by the United States is the first component to be transported along the ITER itinerary. At least 250 "highly exceptional loads" are expected during the construction and assembly phases of ITER.

Since the completion of its metal structure the Assembly Building is the tallest building on the ITER platform, rising 60 metres above ground level. Here pre-assembly activities will be carried out on the principal tokamak components prior to installation.

Bernard Bigot (smiling) takes the helm as the ITER Organization's third Director-General in March 2015. He establishes the Executive Project Board (pictured) as a forum for tightened collaboration with the Domestic Agencies.

The first of five drain tanks for the tokamak cooling water system arrives from the United States.

Procured by Europe and manufactured in Spain, two 100 m³ tanks for the water detritiation system are delivered in the spring of 2015.

Since 2011, Open Doors Days have been the occasion to visit the construction site, meet ITER specialists, and ask questions about the world's largest collaborative effort in science. ITER holds them twice a year.

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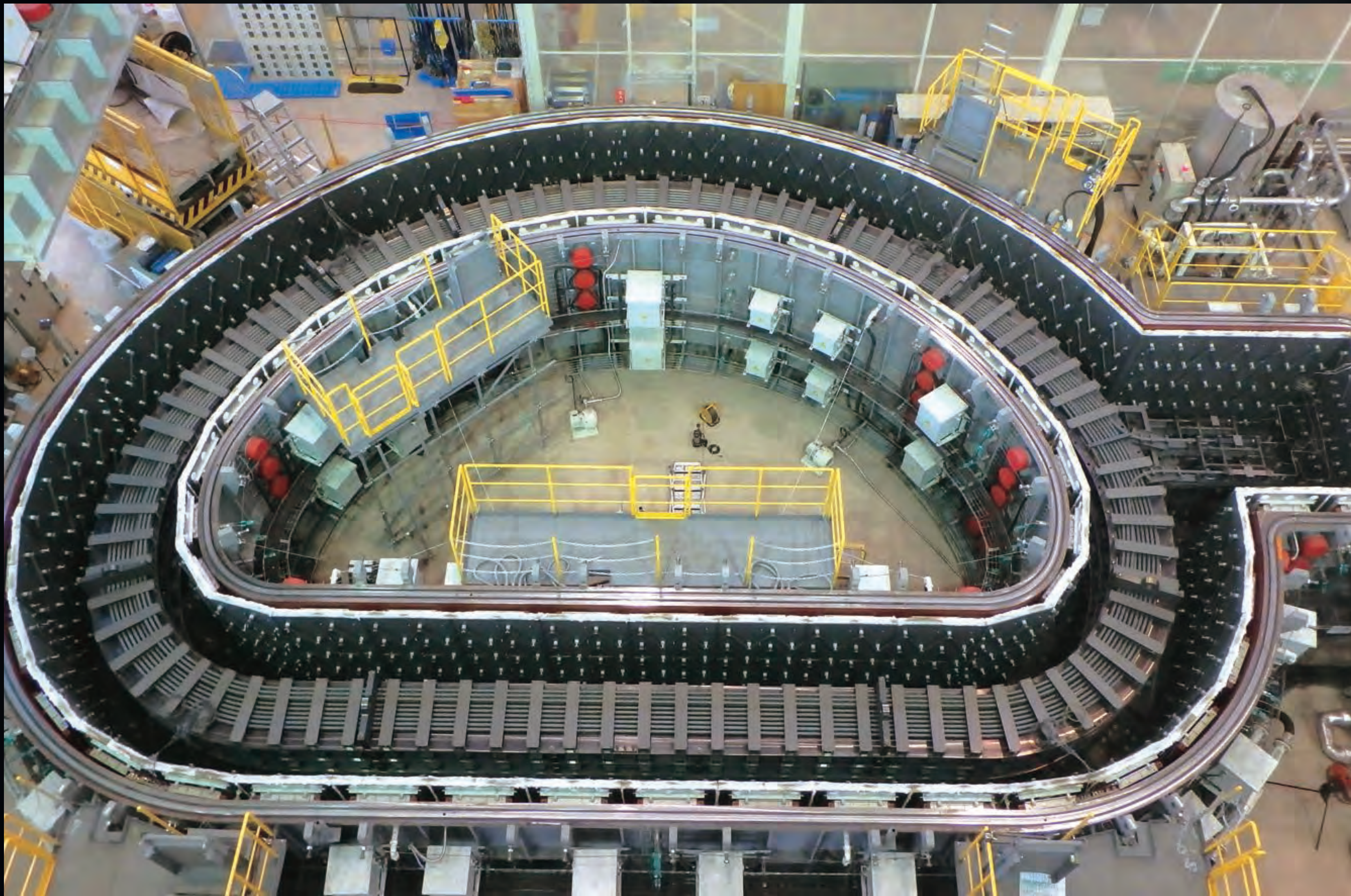
2015

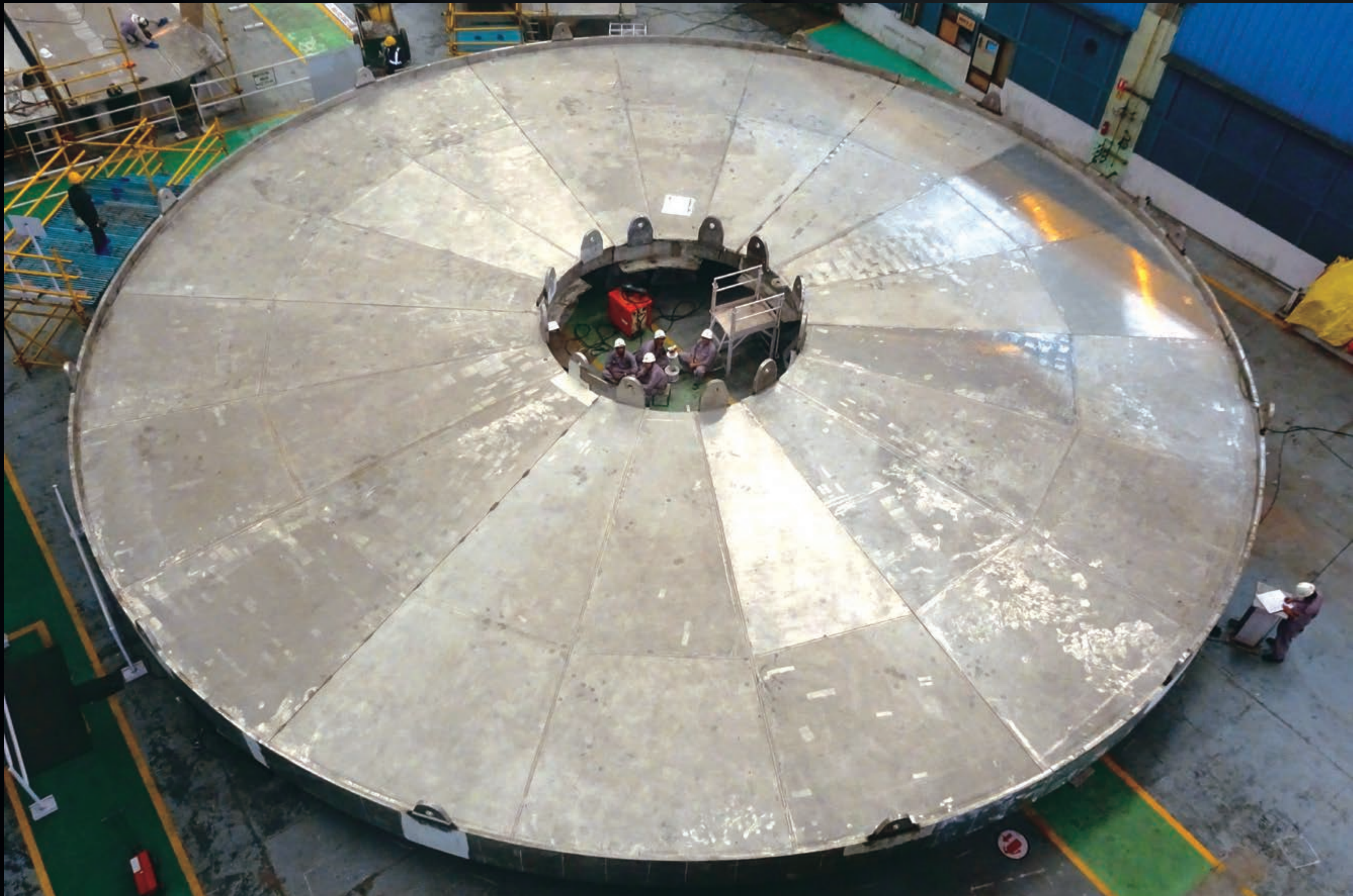
Cryostat feedthroughs cross through the cryostat and bioshield to provide a passageway to the ITER magnets for cooling pipes, power and instrumentation cables. This 10-metre prototype was manufactured at the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP).



Toroidal field coil windings must be heat treated at 650 °C for 100 hours to react tin and niobium and form the superconducting compound Nb3Sn. In this furnace at Mitsubishi Heavy Industry's Futami factory, seven toroidal coil windings have been successfully heat treated.

Drain tanks for the tokamak cooling water system are in fabrication at Joseph Oat Corporation in Camden, New Jersey.

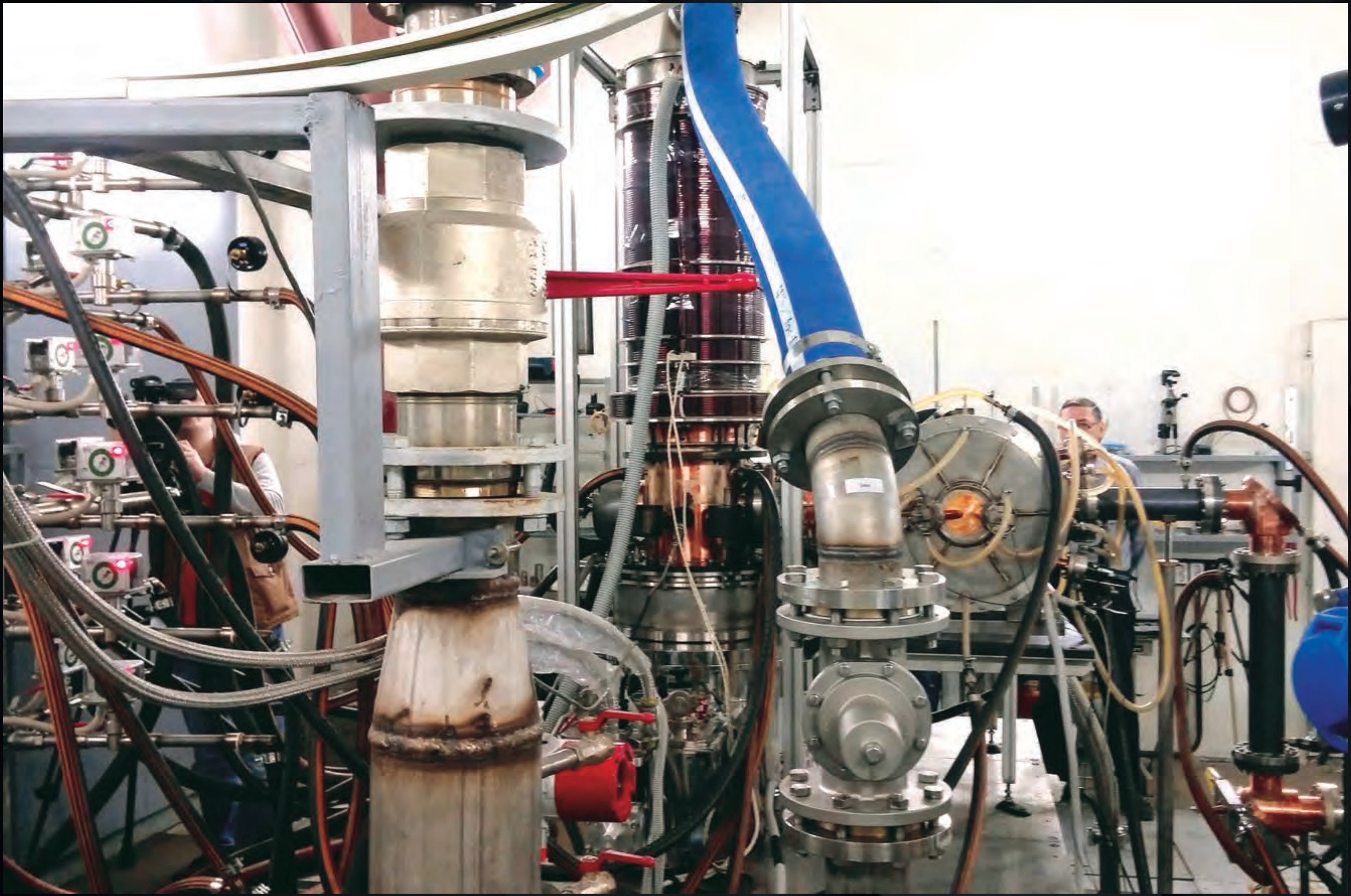
Europe is responsible for procuring the remote handling systems for the ITER divertor. Pictured: the final demonstration of cassette remote handling is successfully performed at the DTP2 Divertor Test Platform facility in Tampere, Finland.



At the Larsen & Toubro Ltd factory in Hazira, India, Tier 1 of the cryostat base is assembled on the shop floor to verify tolerances before being shipped in six 60° segments to the ITER site. The cryostat base is the heaviest single component of ITER assembly (1,250 tonnes).

In June, specialists from the Cable Institute (JSC VNIIKP) jacket and compact the last production length of Russian toroidal field conductor at the Institute of High Energy Physics in Protvino, Russia. This milestone marks the end of a five-year campaign to manufacture 28 production lengths, amounting to more than 120 tonnes of material.

The US central solenoid winding line is inaugurated in April 2015 at the General Atomics Magnet Technologies Center in Poway, California. Winding activities have begun on the magnet packs for the six central solenoid modules plus one spare.



A gyrotron prototype successfully passes factory acceptance tests at Gycom Ltd in Nizhny Novgorod, Russia. These energy-generating devices will inject powerful microwave beams into the ITER vacuum vessel to heat the plasma and drive plasma current.

Around the three-metre-thick ITER bioshield in the centre is a wider circle formed by 18 giant columns that will rise 30 metres to provide structural support to the Tokamak Building.

The cavernous spaces in the basement of the Tokamak Building will completely fill up with pipes, cables, feeders and busbars as the tokamak systems are installed. The equipment will be welded to the embedded plates that can be seen in the floor, walls and ceiling.

Four of ITER's six ring-shaped poloidal field coils will be manufactured by Europe in this on-site facility, where tooling and process qualification is underway.

In 2016, approximately 1,500 workers are involved in the construction of the ITER scientific installation. Work is performed in two-and-a-half daily shifts.

Cryogenic technology will be used extensively at ITER to create and maintain low temperature conditions for the magnet and vacuum pumping systems. The required cooling power will be produced in the cryoplant and distributed through a vast network of pipes, pumps and valves.

Large components like this cryoplant tank procured by Europe are shipped by sea to the Mediterranean port of Fos-sur-Mer before continuing along a specially adapted road itinerary to the ITER site.

2016

Double pancakes – the building blocks of the toroidal field winding packs – are produced in series at Mitsubishi Heavy Industries in Japan, passing through winding, insulation and finally impregnation stages.

This 300 MVA step-down transformer is one of three that have successfully passed factory acceptance tests in China for ITER's pulsed power electrical network. The first transformer reaches ITER in 2016.

D-shaped toroidal field coils will create the magnetic field that confines the ITER plasma. Europe has successfully completed its first winding pack - the central superconducting core that will be inserted into a structural case.

Pushed and pulled by powerful tugs and escorted by a patrol boat of the French Gendarmerie Maritime, the barge and its load (trailer plus a 155-tonne girder) approaches the entrance of the narrow channel that leads into the inland sea Étang de Berre.

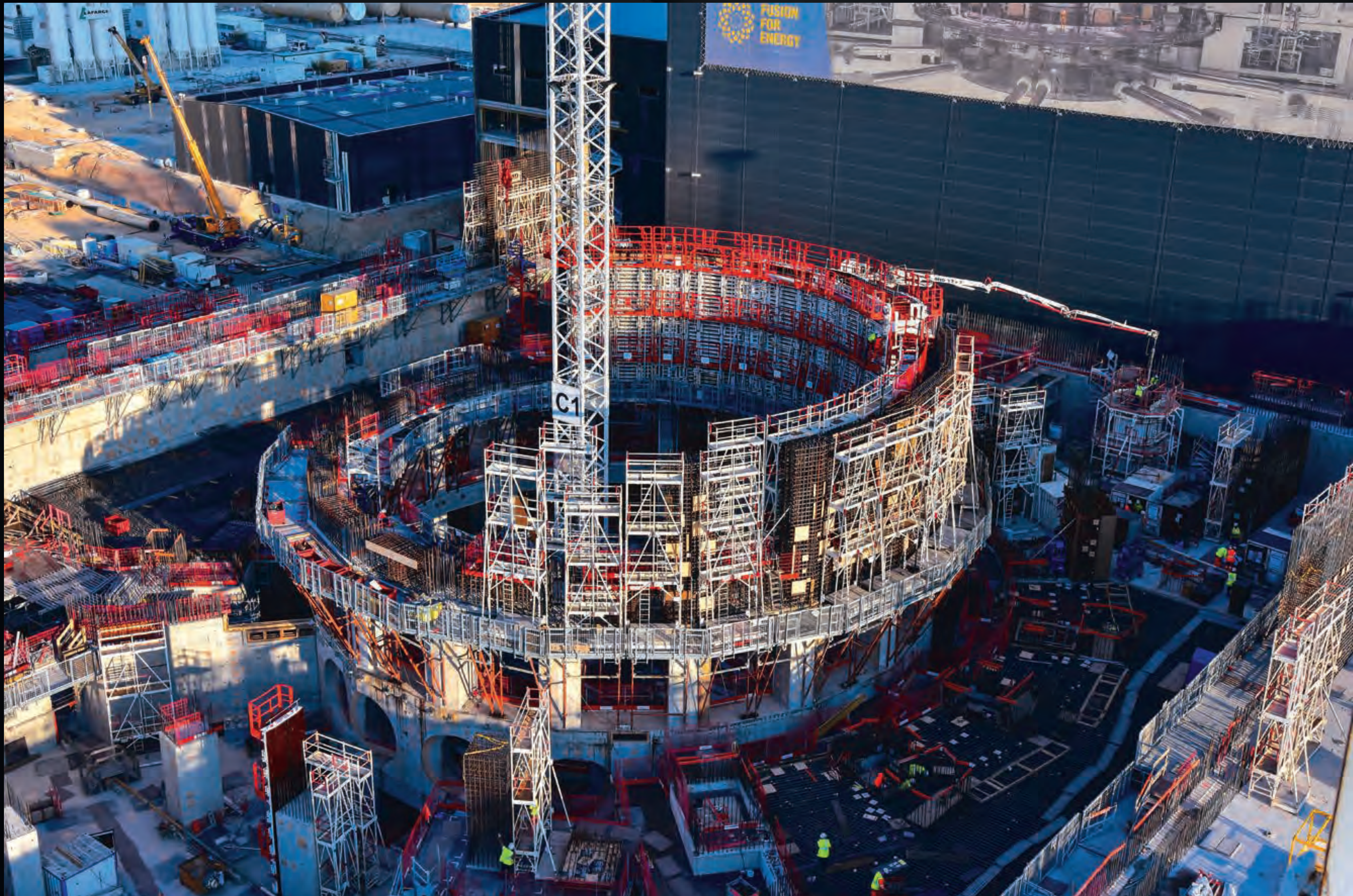
A thin barrier of stainless steel (10-20 mm), actively cooled and covered with a low-emissivity coating of silver, will protect the magnet coils from thermal radiation. At SFA Engineering in Changwon, Korea, welding is underway on an outboard sector of the vacuum vessel thermal shield.

In St. Petersburg, Russia, specialists of the Efremov Institute and the Srednenevsky shipyard have completed the first poloidal field double pancake winding. Eight double pancakes will be stacked to form poloidal field coil #1, the smallest of ITER's ring-shaped magnets.

A few hours before the last leg of the journey from their manufacturing site in Spain, twin girders for the double overhead travelling crane are parked along the ITER itinerary. Convoys travel at night to limit impact on the local population.

A massive crawler crane with a lifting capacity of 1,000 tonnes raises the steel girders of the Assembly Hall travelling cranes into position by passing hooks and cables through an opening in the roof.

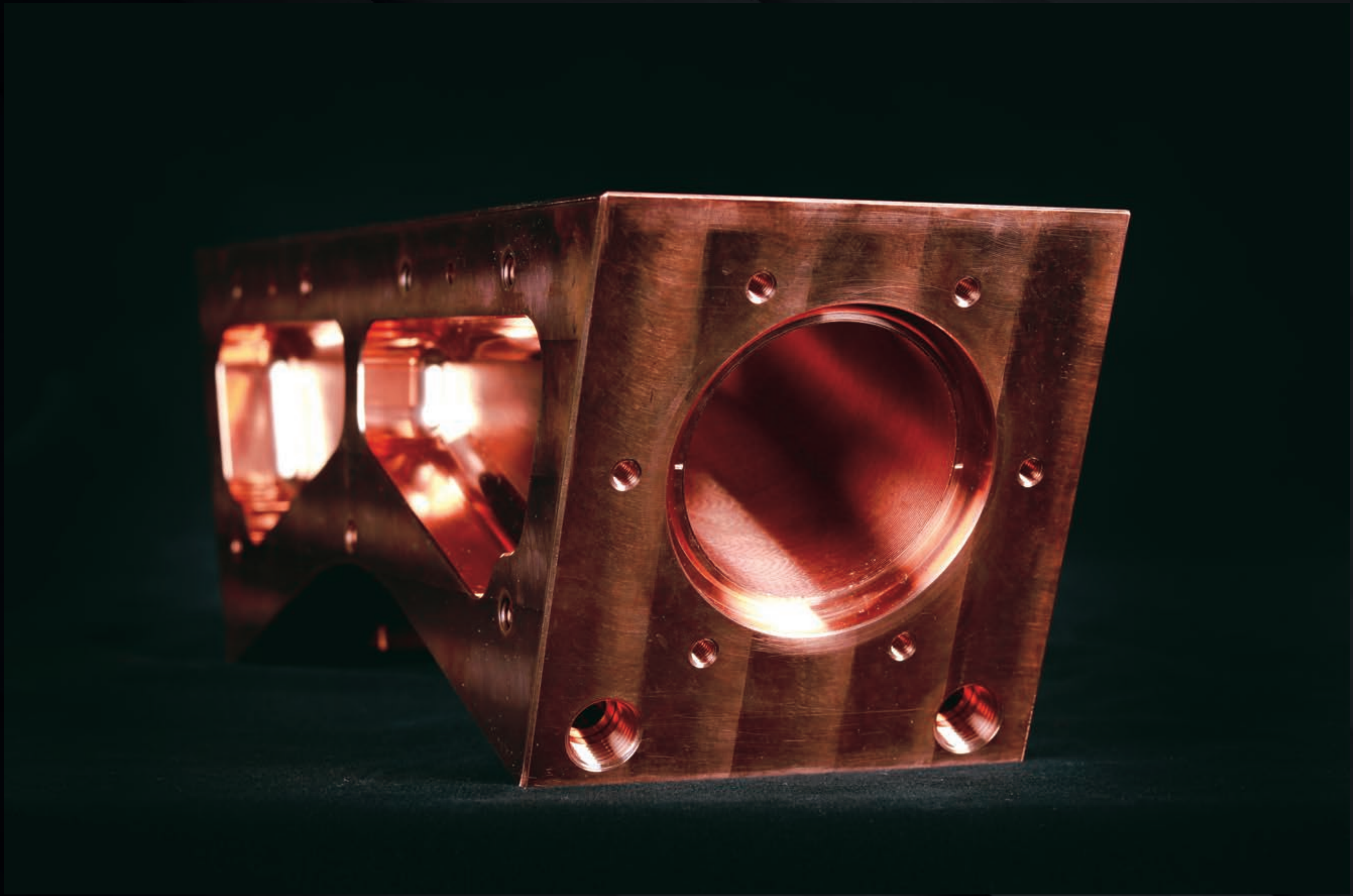
Like cardinals assembled for a conclave, participants in the 2017 ITER Business Forum sit facing each other in the Papal Palace in Avignon, France.



Concrete pouring is underway to complete the ITER bioshield before the first captive components are installed. The assembly of the world's largest tokamak will take place from bottom up – starting with the cryostat base and ending with the cryostat lid.

Fabrication has begun on poloidal field coil #5 in Europe's on-site manufacturing facility, after all tooling and process qualification activities were completed. PF5 measures 17 metres in diameter.

Six metres overhead, the mockup of a high voltage deck is tested successfully in a laboratory at HSP GmbH, Germany. The cube is 1/15th of the size of the deck that will be integrated into the MITICA testbed, currently under construction at the ITER Neutral Beam Test Facility in Padua, Italy.

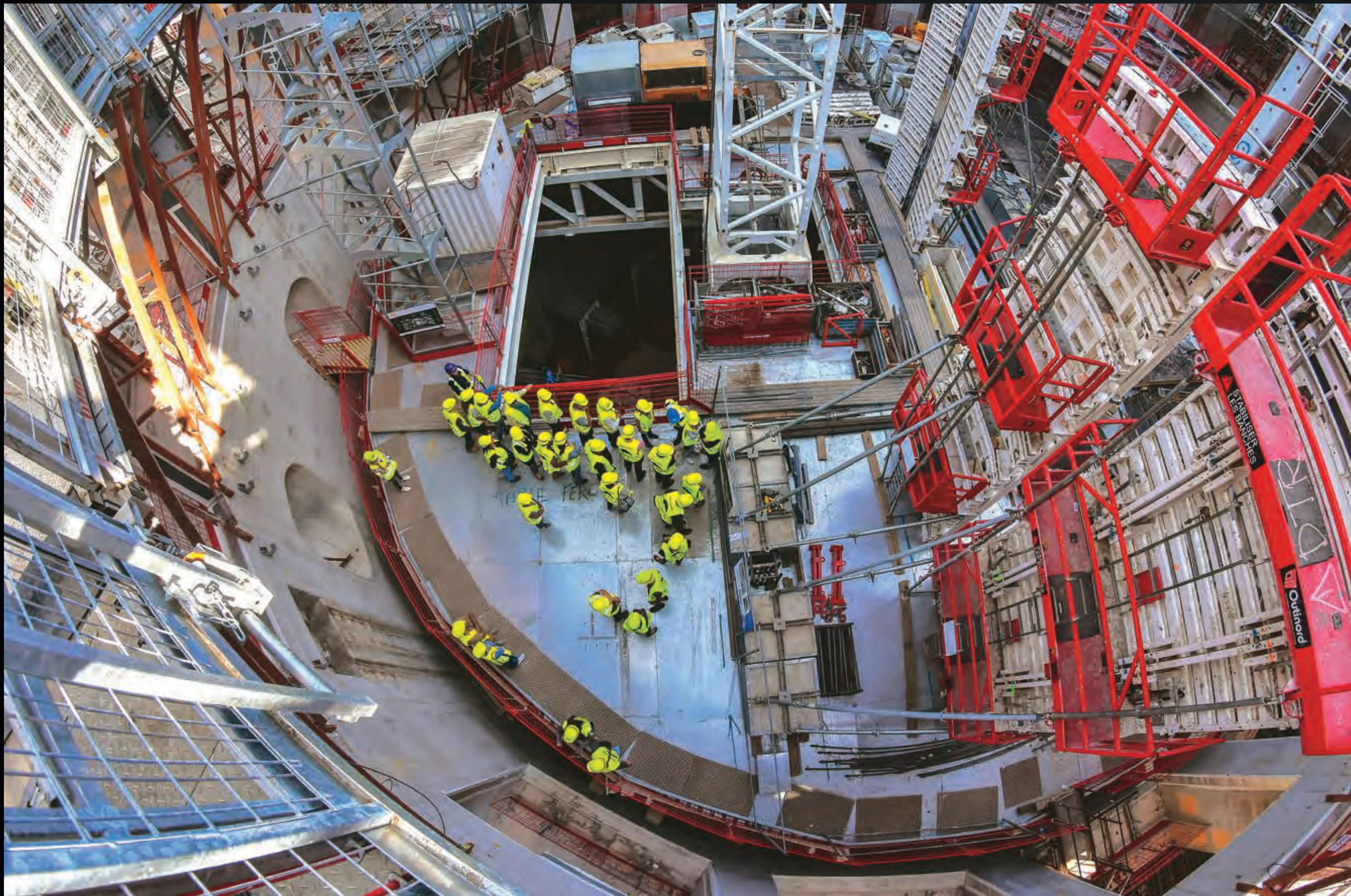


This "mitre bend" waveguide prototype is part of the electron cyclotron transmission lines that will route microwave beams from the Radio Frequency Building to the tokamak, where they will deliver 20 MW of heating power to the ITER plasma. Transmission line R&D, design and fabrication is under the responsibility of the US Domestic Agency.

The ITER construction platform, seen from a worksite crane. The Assembly Hall is the most prominent feature, with the Tokamak Complex under construction right in front of it. Plant systems will be housed in buildings under construction across the rest of the platform. The poster on the Assembly Hall shows a cutaway of the ITER tokamak at 70% of its actual size.

The ITER cryostat – the leak-tight vacuum container that will act as a thermos to insulate the ultra-cold superconducting magnets from the outside environment – is being assembled in a dedicated facility on site by contractors to the Indian Domestic Agency.

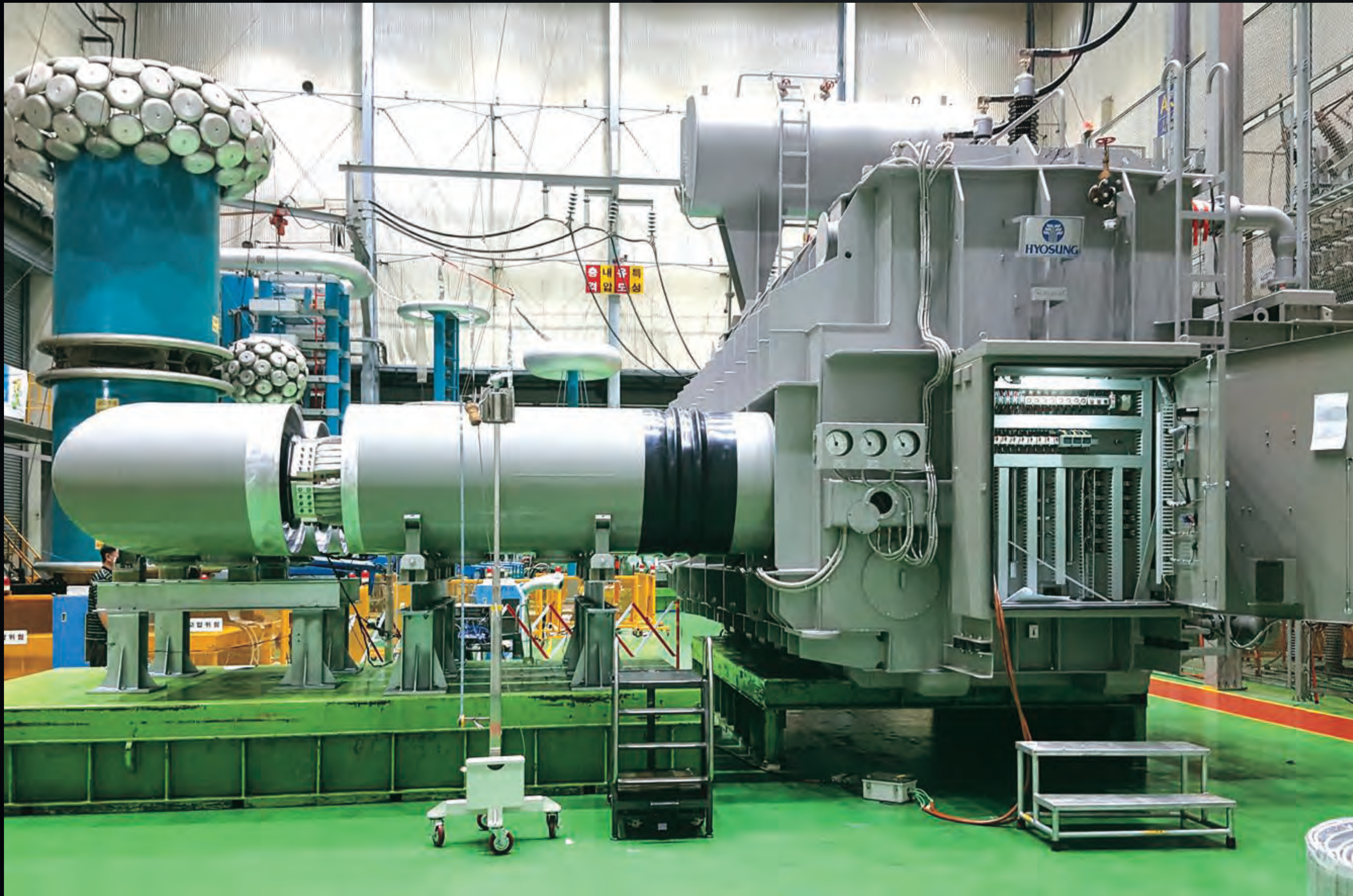
Japanese contractors have successfully completed the fabrication of 43 kilometres (700 tonnes) of niobium-tin cable-in-conduit superconductor for ITER's central solenoid magnet. Here, the team is pictured at the Wakamatsu factory of Nippon Steel and Sumikin Engineering Co., Ltd. in Kitakyushu.



The ITER Organization and the European Domestic Agency team up twice a year to welcome visitors to the construction site on Open Doors Days. In the most technical areas of the Tokamak Building, only small groups are admitted at a time.

Manufactured in France by Air Liquide, this helium "cold box" – installed with two others in the cryoplant during the year – will provide insulation for the key components of the liquid helium plants.

The ITER Assembly Hall is the space for the pre-assembly of all main machine components. As soon as the Tokamak Building is completed (far end) the temporary wall will be removed, giving direct access to the tokamak assembly pit.

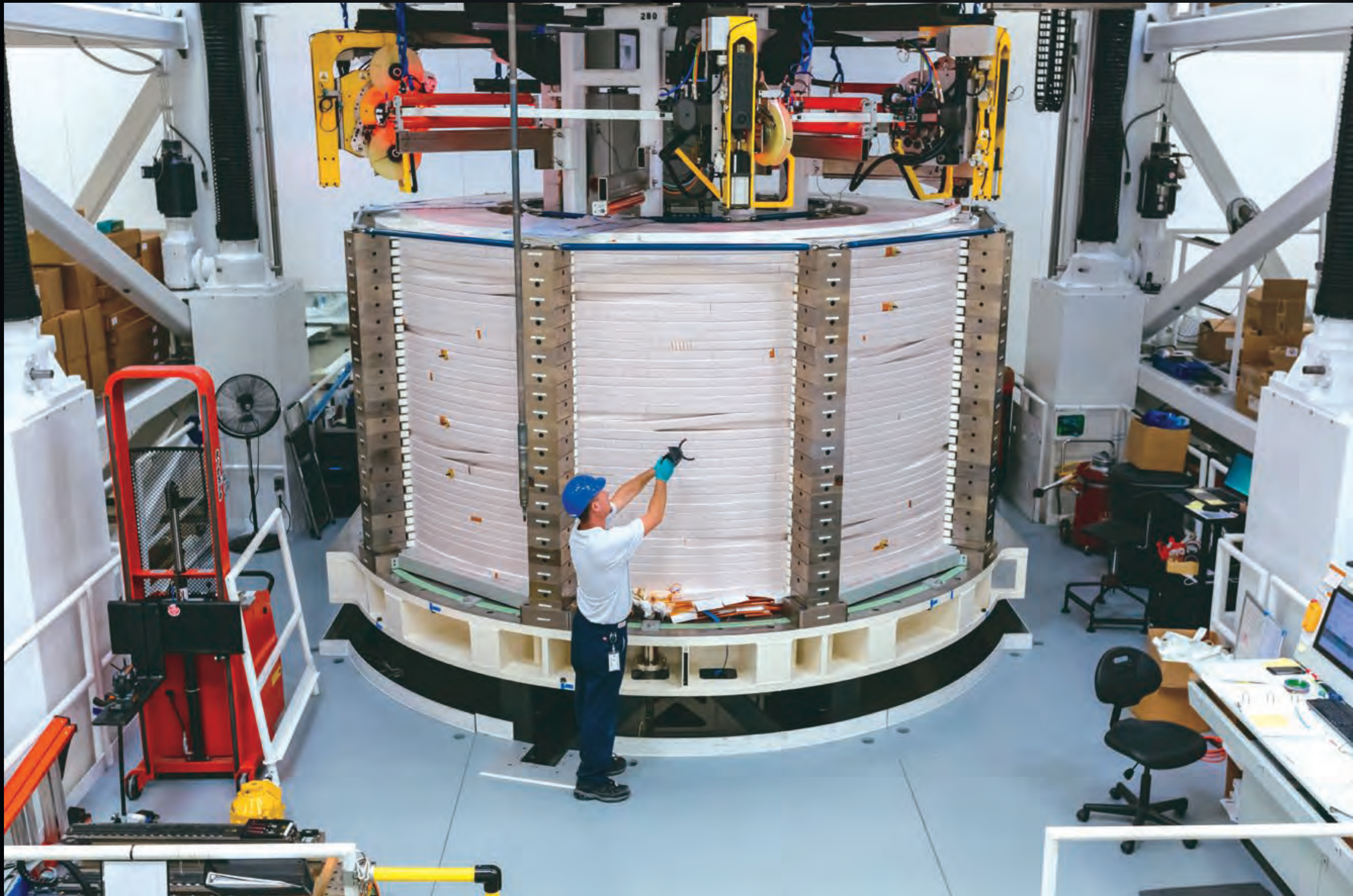


A 130-tonne converter/transformer is tested at the Korean firm Hyosung. It is one of 12 that will be delivered to ITER to transform current for the central solenoid magnet system.

Inside the huge well of the ITER bioshield, construction teams are working on different levels simultaneously. Soon, a temporary steel cap—whose purpose is to protect teams below while allowing work to continue above—will split the volume in two.

Located between the electrical switchyard (background) and the Tokamak Complex, the Magnet Power Conversion buildings will furnish DC current to 10,000 tonnes of superconducting magnets.

The first batches of these large water-cooled DC busbars, which will feed power to ITER's superconducting magnet coils, have already been received at ITER. Russia's Efremov Institute is manufacturing and shipping 5.4 km of these high-tech components for a total weight exceeding 500 tonnes.

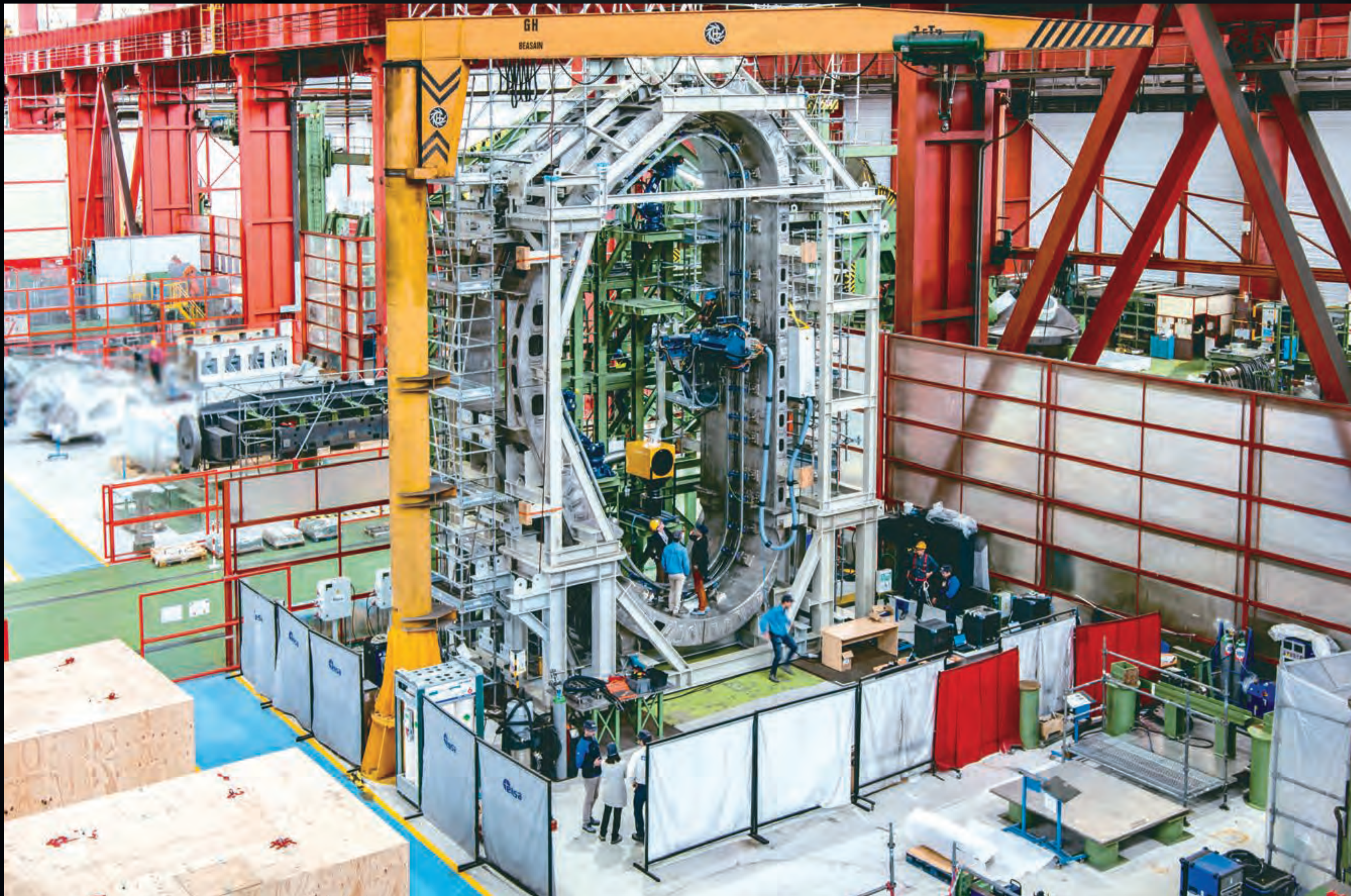


Following heat treatment, the first of six independent magnets for ITER’s central solenoid has successfully passed the turn insulation phase at the General Atomics Magnet Technologies Center near San Diego, California. The 1,000-tonne central solenoid, formed from six stacked modules, will "beat" from the very heart of the ITER machine.

The ITER Organization, which was established by international agreement in November 2006, formally came into existence eleven months later as ratification procedures were concluded by all Members. In November 2017, the ten-year anniversary was celebrated at ITER Headquarters.

Doric or Ionic? Neither. What looks like broken columns from a Greek temple are in fact steel ingots for the ITER cryostat, cooling on a bed of black sand inside the Larsen & Toubro Ltd foundry in Hazira, India.

The sector sub-assembly tools that will permit the creation of 1,350-tonne vacuum vessel sub-assemblies, or "modules," weigh 800 tonnes and stand 22 metres tall. Pictured here is tool SSAT-1, supplied by Korea, that will soon have an identical twin in the Assembly Hall.



This mock-up of an ITER vacuum vessel sector stands as high as a five-storey building in ENSA's special projects workshop in the outskirts of Santander, Spain. With the exception of sector width (10 degrees versus 40 degrees) it mirrors the future reality of ITER down to the smallest detail. It will be used to develop and test welding tools.

2018

Procurement for the ITER cryolines—the highly sophisticated multi-process pipes that transport cooling fluids—is shared by France's Air Liquide and India's INOXCVA (pictured here). ITER will have approximately 5 kilometres of cryolines ranging from 25 to 1000 millimetres in diameter.

It is close to midnight in the basement of the ITER Tokamak Building and the first plot of the tokamak "crown" is to be poured. The operation is of strategic importance: the crown will support the combined mass of the tokamak and its encasing cryostat (23,000 tonnes) while transferring the forces and stresses generated during plasma operation to the ground.

The lid is raised to the top of the bioshield in March, becoming a protective roof for all activities below. Teams can now work freely in the 30-metre-deep machine assembly arena.

On the floor of the tokamak pit, European contractors prepare to pour the concrete crown – the ring wall foundation that will support the full weight of the machine.

ITER Headquarters is a busy hive, where approximately 500 project collaborators work and meet daily.

Hyundai Heavy Industries is manufacturing four of ITER's nine vacuum vessel sectors. Pictured: technicians are inserting neutron shielding blocks into one of four sector #6 segments.

Deep in the bowels of the Tokamak Building, workers are busy lining the floor and the lower walls of the drain tank room with stainless steel panels. In case of a leak in the tokamak cooling water system, the lining will act as a ''drip pan'' to contain contaminated effluents.

A second vacuum vessel sector handling tool has been delivered by Korea and installed in the Assembly Hall. The twin tools will be load-tested in early 2019.

This plasma-facing component of the ITER divertor – a full-scale prototype of the inner vertical target manufactured by Ansaldo Nucleare and ENEA in Italy – is about to be tested under high heat flux at the Divertor Test Facility in Russia.

A 10-metre, 6.6-tonne magnet feeder segment from China is the first machine component to be installed in the tokamak pit.

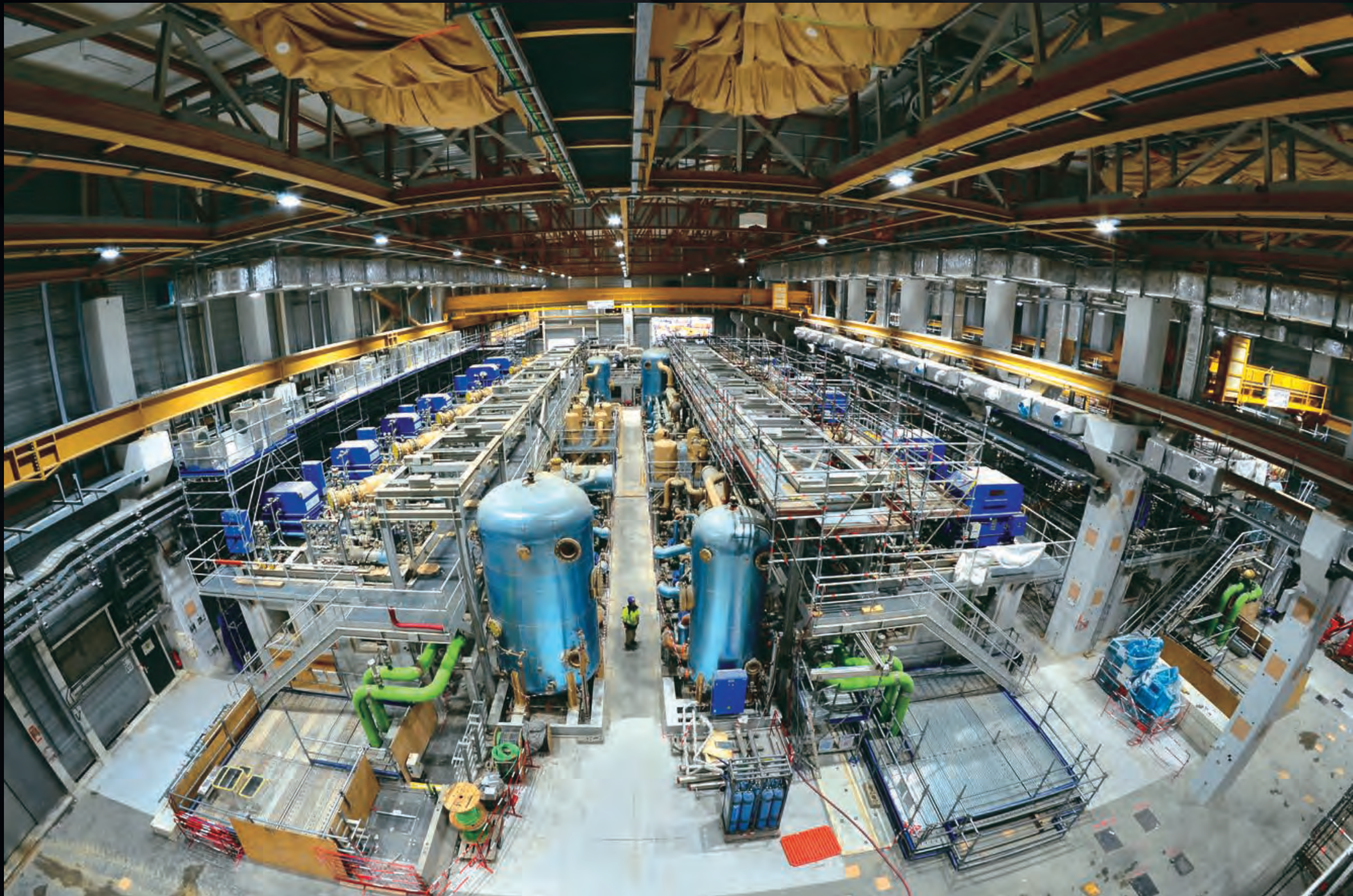
Now painted in white, the lowest basement level of the Diagnostic Building is ready for handover to contractors for the beginning of systems installation. Embedded plates—for the attachment of system supports—are visible on all surfaces.

Hot helium leak tests on this 2.8-tonne blanket shield block prototype have successfully confirmed its suitability for ITER's ultra-high vacuum environment.

Divertor cassette bodies are the "chassis" of the divertor assemblies – eight-tonne structures that will support plasma-facing targets, diagnostics, operational instrumentation and cooling. Pictured is a real-size prototype manufactured in Italy by Water Tosto.

Extending out from each vacuum vessel port are port stub extensions that will be welded to the vacuum vessel sectors before the assembly of the main vessel in the pit. Russian contractors are producing extensions for the ITER upper ports in series.

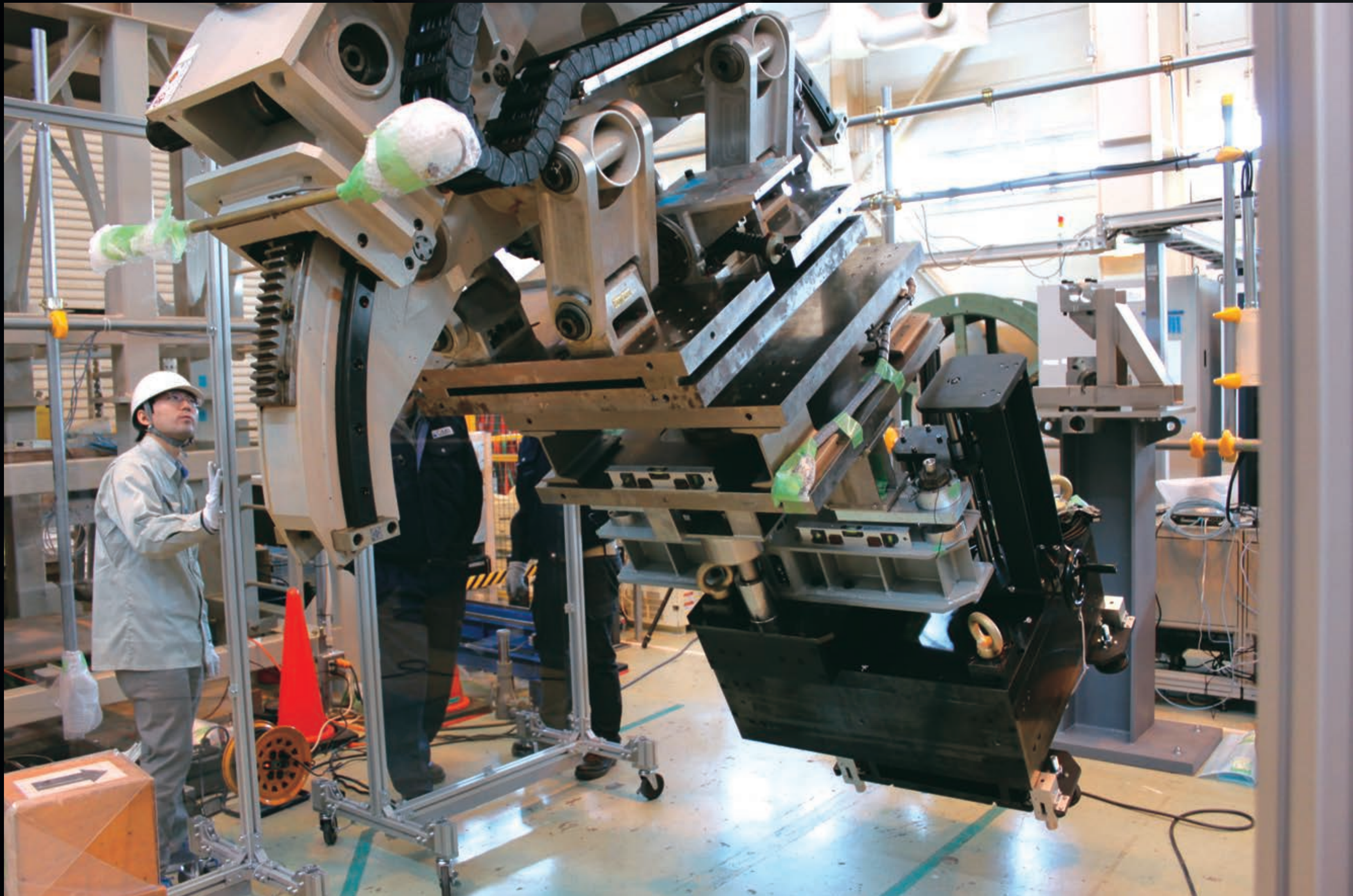
Raw concrete in the tokamak assembly pit has given way to the smooth shiny surface of many layers of white paint. The pit's vast volume (25,000 m³) is nearly ready to receive the first major machine components.



As large as two football pitches, the ITER cryoplant will provide cooling fluids to 10,000 tonnes of superconducting magnets, eight massive cryopumps, and thousands of square metres of thermal shielding.

Nested amid rolling hills and fields along the Durance River valley, ITER is a futuristic enclave in an unchanging environment. To the south, the Mediterranean is less than 70 kilometres away. To the north, the Massif des Écrins, culminating at 4,000 metres, is a mere two-and-a-half-hour drive.

Several large semi-circular components have been delivered for the magnet feeder system that will transport cryogens and electrical power to the bottom correction coil magnets. The feeder sections seen travelling here will be installed inside the cryostat base.



Although not as powerful as the Infinity Gauntlet of comic book fame, the robotic bolting tool that will be used to install ITER's in-vessel blanket modules is impressive. It will provide 10 kilonewton/metres (kNm) of torque to tighten the massive bolts of the blanket first wall panels.

At different stages of fabrication, the top or bottom of a central solenoid module must be accessible. This turnover tool at General Atomics (California) makes easy work of flipping the 110-tonne components.

Workers head to the cafeteria for a quick meal before resuming their shift. Since construction began in the summer of 2010, an estimated 15,000 people from 5,000 companies have been involved in the myriad activities that building ITER requires.

The amount of water that needs to be circulated within the heat rejection system is huge—in the range of 10 m³ per second. Thirteen vertical turbine pumps, submerged deep in the basins, are tasked with moving one tonne of water per second per pump. Pictured: the installation of a 10-metre-long shaft for one of the turbines.

At the Larsen & Toubro factory in Hazira, India, elements of the cryostat top lid are in fabrication. When completed, they will be sent to the Indian Domestic Agency's workshop at ITER for assembly.

Twice a year, the ITER Organization hosts meetings of the ITER Council, which convenes to review the overall progress and performance of the project. Delegations from the Members are composed of high-level representatives, experts and translators.

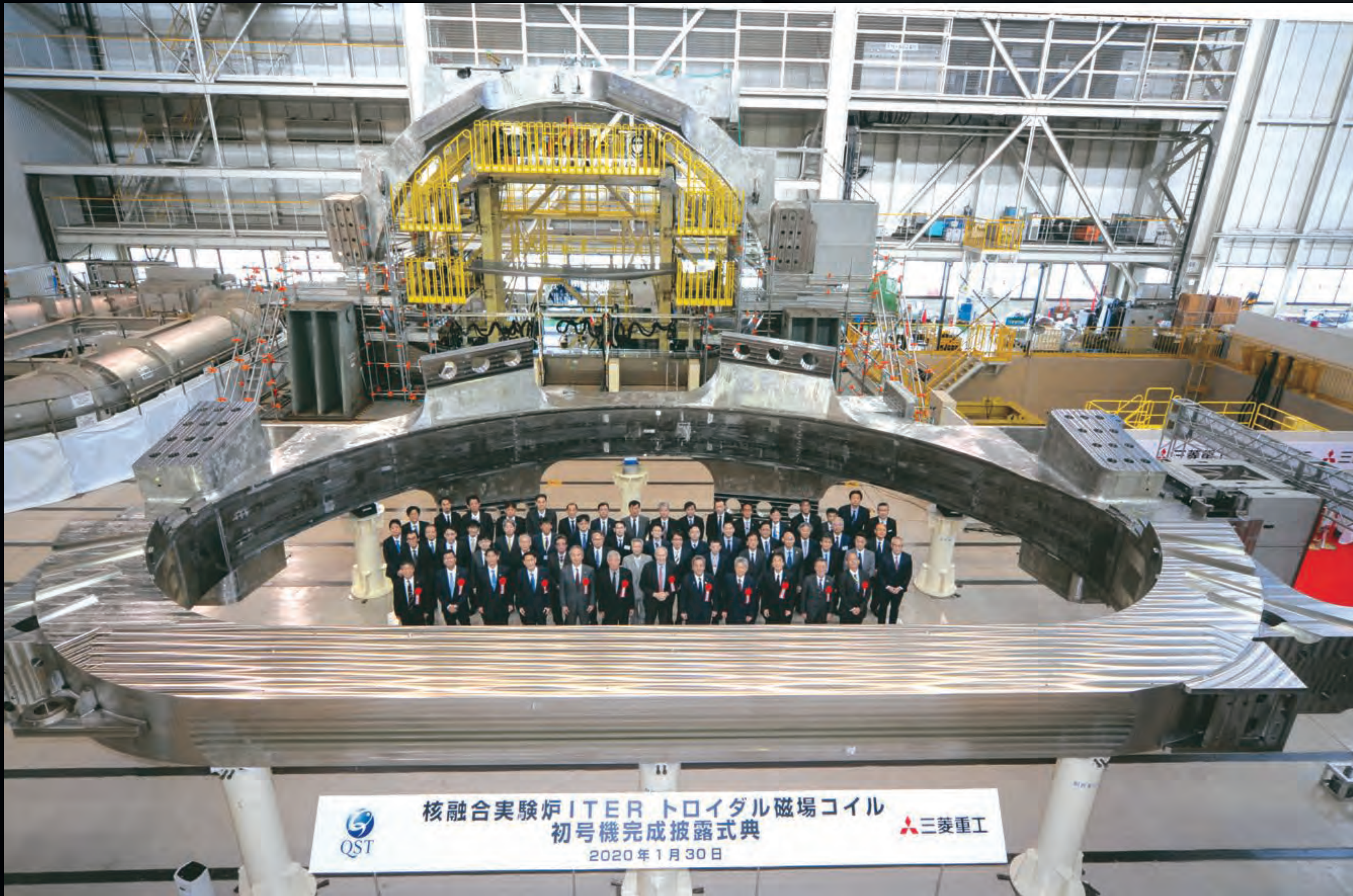
Over nine days in December, five pre-assembled modules for the roof of the crane hall are lifted into place. The complete roof structure—20 tall pillars and roof modules included—weighs approximately 2,000 tonnes.

The Tokamak Building will soon have a roof and an important new phase can start: the assembly of the ITER machine.

ITER transitions to a new way of working in 2020 in the context of the Covid-19 pandemic. Strong measures are implemented to protect staff, such as teleworking, while critical activities such as machine assembly are maintained on the worksite.

Five kilometres of water-cooled, steel-jacketed busbars will deliver DC power to the ITER magnets. The most powerful will carry close to 70 kiloamps of current—about 7,000 times the power of an average washing machine cable.

2020



Japan's National Institutes for Quantum and Radiological Science and Technology (the procuring agency, QST) joins with Mitsubishi Heavy Industries, Ltd. and representatives of the ITER Organization to celebrate the completion of ITER's first toroidal field coil in January.

2020

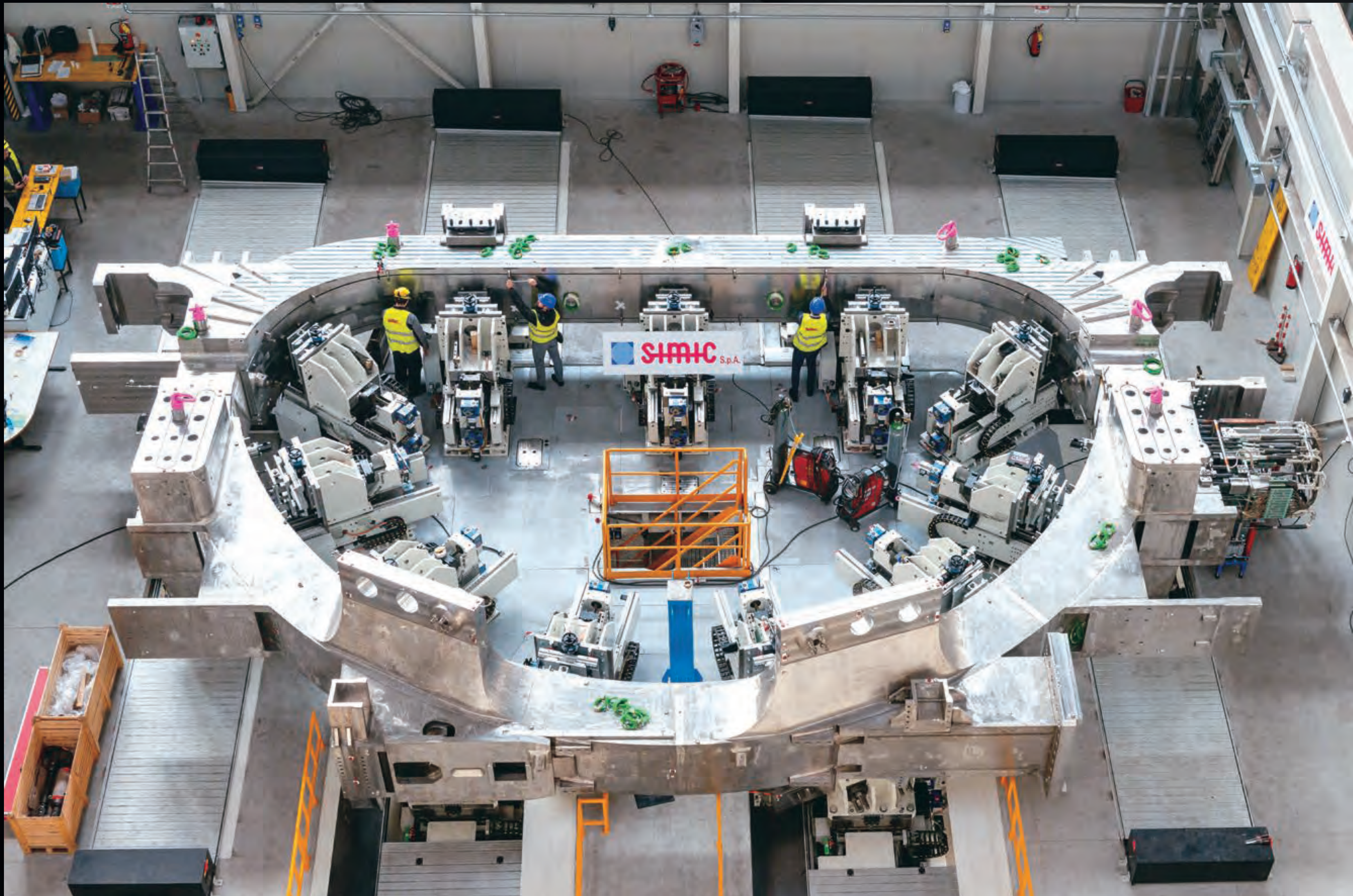
Ten years of planning and fabrication come to an end as Korean Domestic Agency contractor Hyundai Heavy Industries completes the first vacuum vessel sector in April.

2020

A toroidal field coil manufactured in Japan is prepped for loading at the Port of Kobe in April. Quality and safety must be strictly managed not only for coil fabrication but during transportation as well.

Manufactured in China for the European Domestic Agency, poloidal field coil #6 will be the first to be integrated into the ITER machine. Like every highly exceptional convoy along the ITER transport itinerary it is escorted by a full French gendarmerie squadron (approximately 50 people) tasked with securing the operation and managing the closing and reopening of roads.

2020



The first of 10 toroidal field coils to be procured by the European Domestic Agency, Fusion for Energy, is ready for shipment. This is the first deliverable of a decade-long program involving more than 700 people and 40 companies.

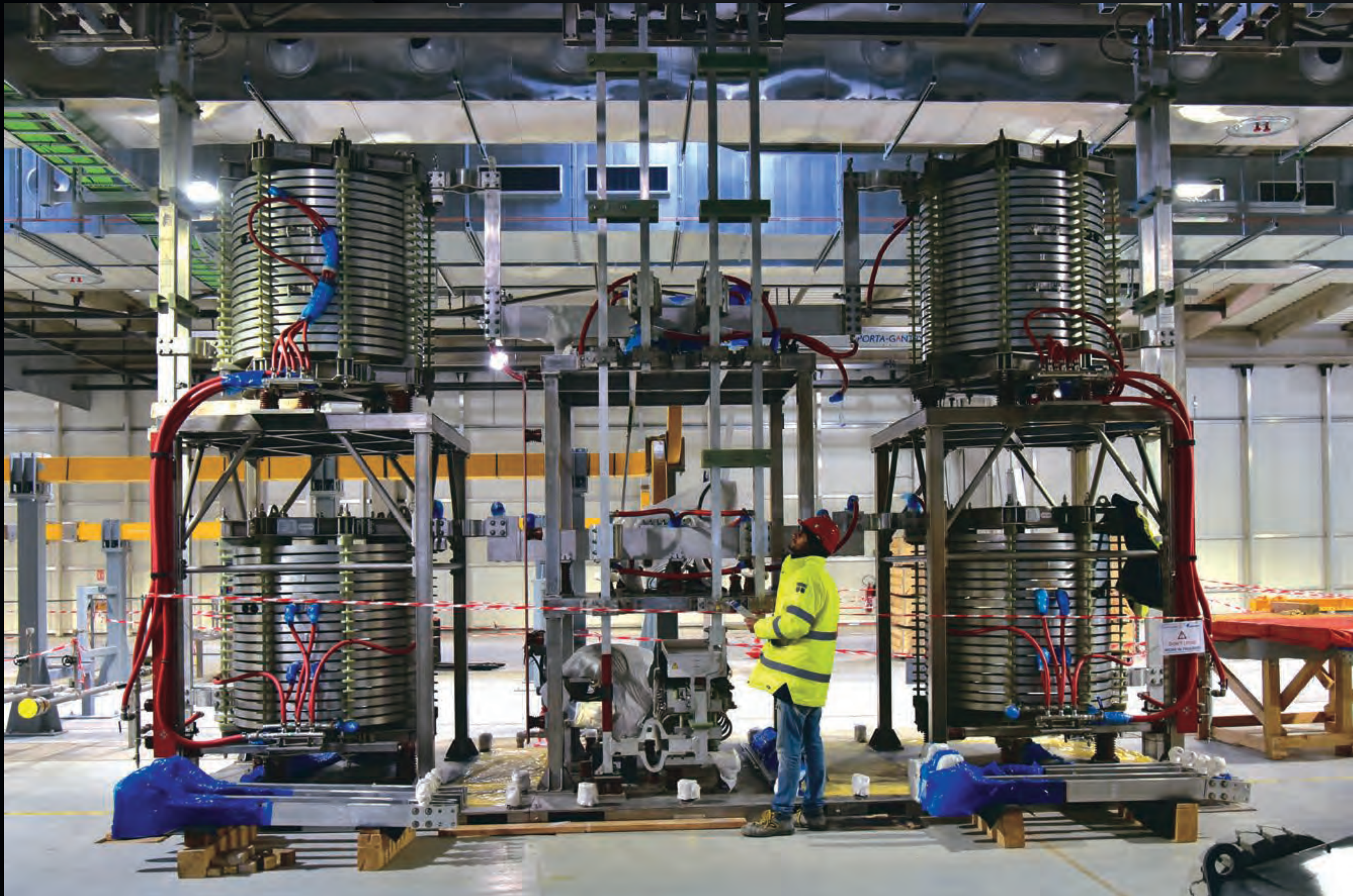
It is a little after 2:00 a.m. on the ITER site and for poloidal field coil #6, the heaviest of ITER's six ring-shaped coils, it is the end of a 10,000-kilometre voyage from China.

The doors of the Cleaning Facility open to admit the cryostat base in May. The assembly phase kicks off with the installation of this 1,250-tonne component, the heaviest of the ITER machine.

Transport company Mammoet, operating as a contractor to ITER global logistics provider DAHER, has developed a prototype trailer whose twin "power packs" deliver the horsepower equivalent of six conventional truck tractors. It will be used for all of ITER's heaviest loads along the ITER itinerary (pictured, toroidal field coil TF12 from Japan).

Ten years after building begins on the ITER site, the first machine component is installed in the tokamak pit in May—the 1,250-tonne cryostat base.

Forty-six port cell doors will seal off every port cell in the Tokamak Building, acting as confinement barriers to shield the environment from the radiation generated by the burning plasma. Each steel door is filled with 7.5 m^3 of high-density concrete.



Twin buildings on site are filling up with equipment to convert AC power to DC power for the superconducting magnets. This strange contraption, a "reactor," creates a magnetic field to filter small spikes in DC waveform before it is fed to the magnetic system.

A new banner celebrates the completion of the Tokamak Building and eight years of collaborative work by the European Domestic Agency, the ITER Organization, and the Vinci Ferrovial Razel-Bec (VFR) consortium. An estimated 1,000 men and women have taken part in construction.

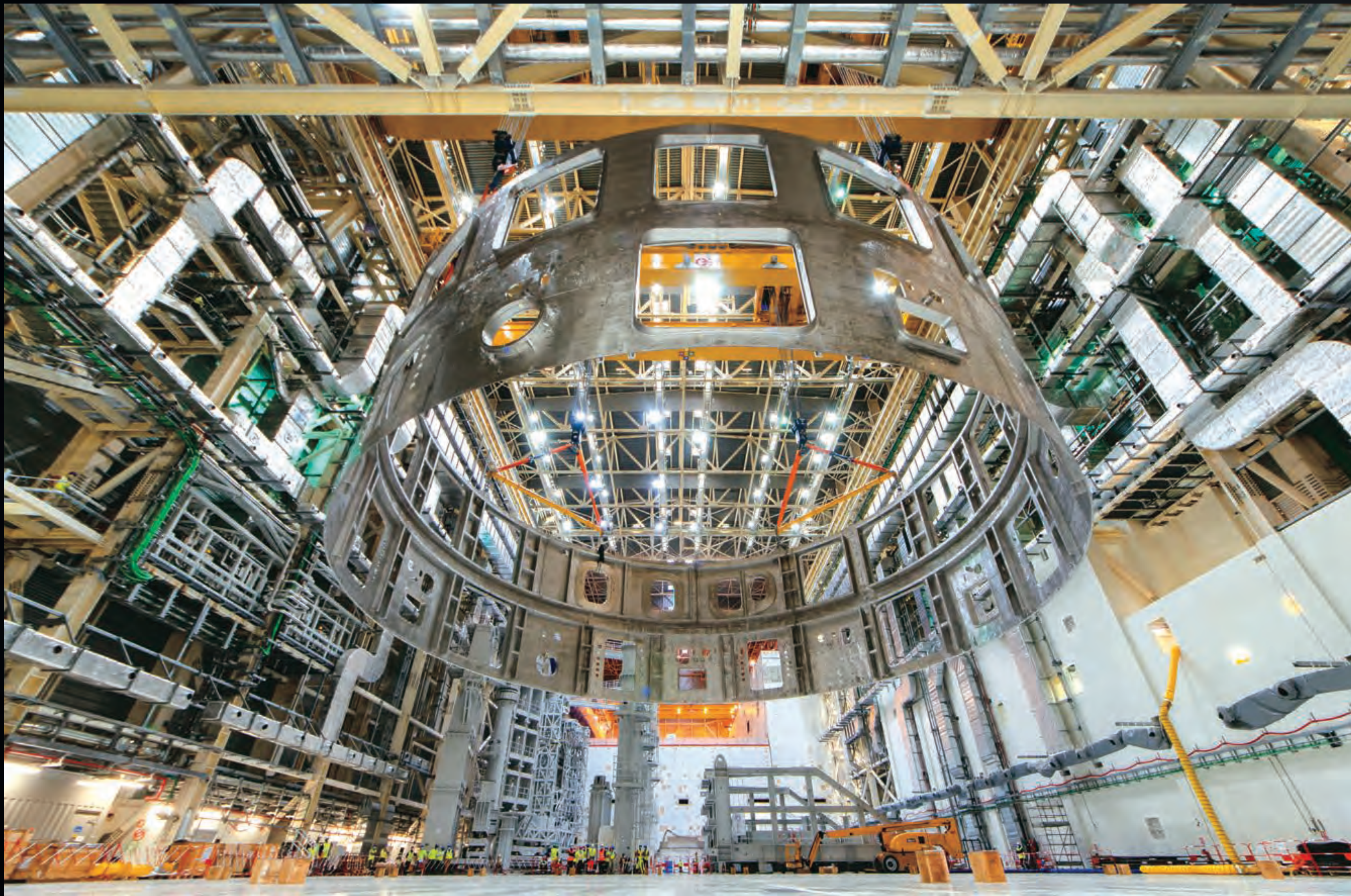
From left to right: two poloidal field coils and a cryogenic chamber for cold testing are visible in this photo taken in July in the European manufacturing facility on site. Cold testing a completed coil is part of a test protocol that allows operators to simulate the thermal stresses and the work conditions that will be experienced by the magnet coils during operation.

Eighteen pillar-like gravity supports will be bolted to the cryostat base to support the toroidal field coil structure, shouldering the dead weight of the tightly integrated magnet system while withstanding the displacement of the coils during cooldown and operation. The cooling system of this unit is about to undergo helium leak testing.

Procured by Korea, the first sector of the ITER vacuum vessel is unloaded at Fos-sur-Mer harbour, on France's Mediterranean coast, on July 2020 after a one-month-long sea voyage.

Organized in the ITER Assembly Hall on 28 July 2020, the kick-off ceremony for machine assembly was hosted virtually by President Emmanuel Macron of France. "ITER is clearly an act of confidence in the future," he said. "At its core is the conviction that science can truly make tomorrow better than today."

2020



After the cryostat base in May, the cryostat lower cylinder is successfully installed in August. The steel ring, although much taller than the base (12 vs 4 metres), is a considerably lighter load at 375 tonnes (vs 1,250).

Each of the heat rejection system's 10 cooling cells is topped by a ''fan cylinder'' hosting a twelve-blade fan that will draw air upward and accelerate the evaporative process used to cool the water arriving from the installation's cooling loops.

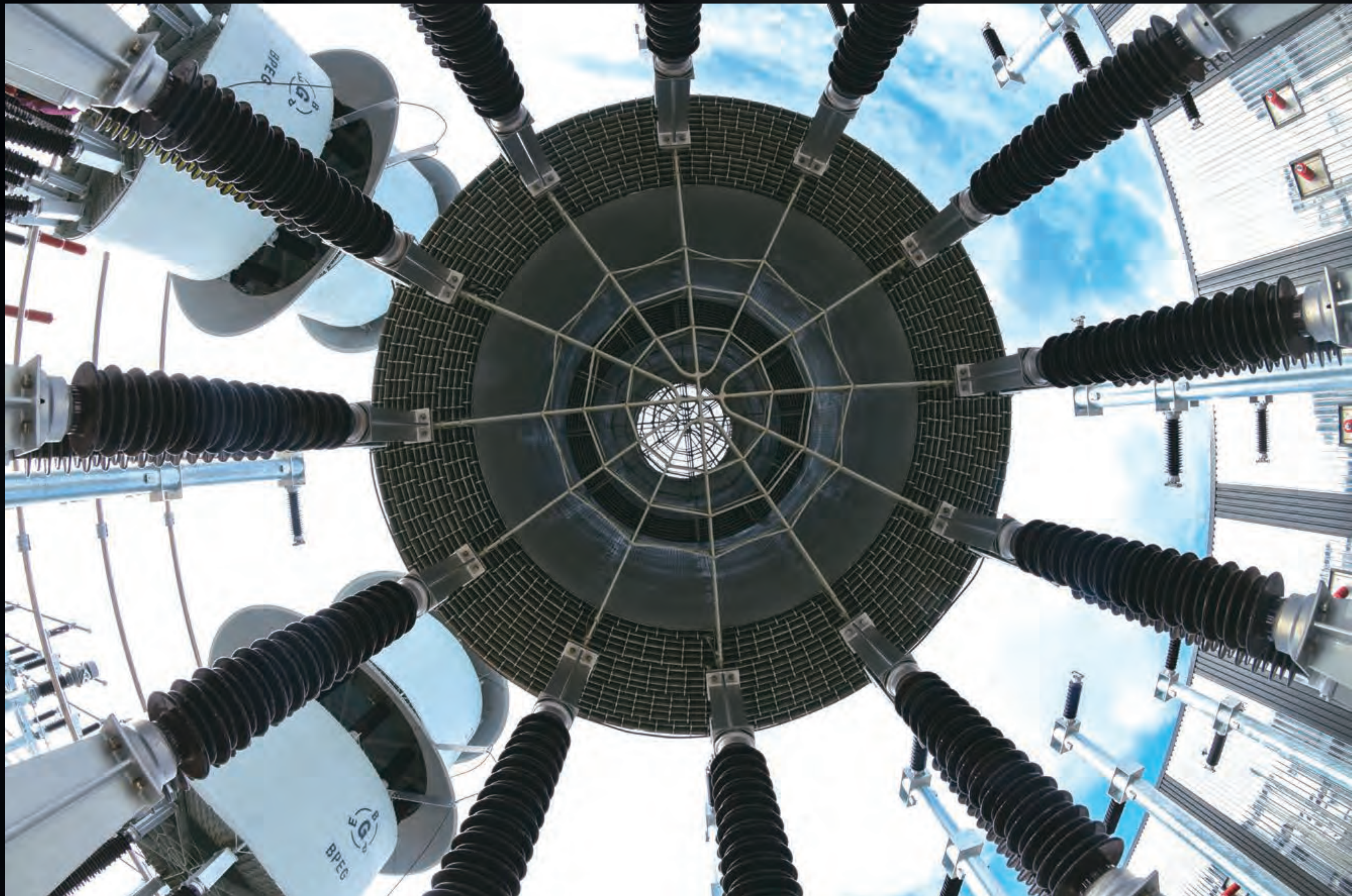
Qualification and fabrication of the electron cyclotron transmission line system is underway in the United States. Pictured are waveguide prototypes.

Six years after the start of fabrication, Korean contractor SFA completes the final 40° sector of the vacuum vessel thermal shield. The stainless-steel panels will be mounted on vacuum vessel sectors before they are lowered into the assembly pit.

The reactive power compensation area accommodates reactors, capacitors, resistors and sensors that aim to smooth the flow of AC current both inside the ITER installation and in the immediate vicinity.

china eu india japan korea russia usa

2020



This alien-looking object is part of ITER’s reactive power compensation and harmonic filtering system, designed to reduce "harmonic distortions" in the AC current that ITER receives from the grid.

The Russian Federation has completed the first full-scale prototype of the divertor dome. One of three divertor targets designed to sustain the top heat flux of the ITER machine (10 to 20 MW/m²), a dome component will be mounted on each of the 54 divertor cassettes.

The first poloidal field coil completes all testing in December. Representatives of the European Domestic Agency Fusion for Energy, manufacturer ASIPP from China, and ASG Superconductors celebrate in front of the vacuum chamber where poloidal field coil #6 spent three months in thermal testing.

The lower cryostat thermal shield is being prepared for installation. The 10-millimetre-thin, 50-tonne component will fit inside the soup-dish-shaped depression of the cryostat base to form a heat barrier protecting the magnets at superconducting temperature. In the ITER Assembly Hall, all segments have been assembled.

The segments of the cryostat lid arrive early in the year from India. They will be assembled and welded on the platform at the far end of the Cryostat Workshop.

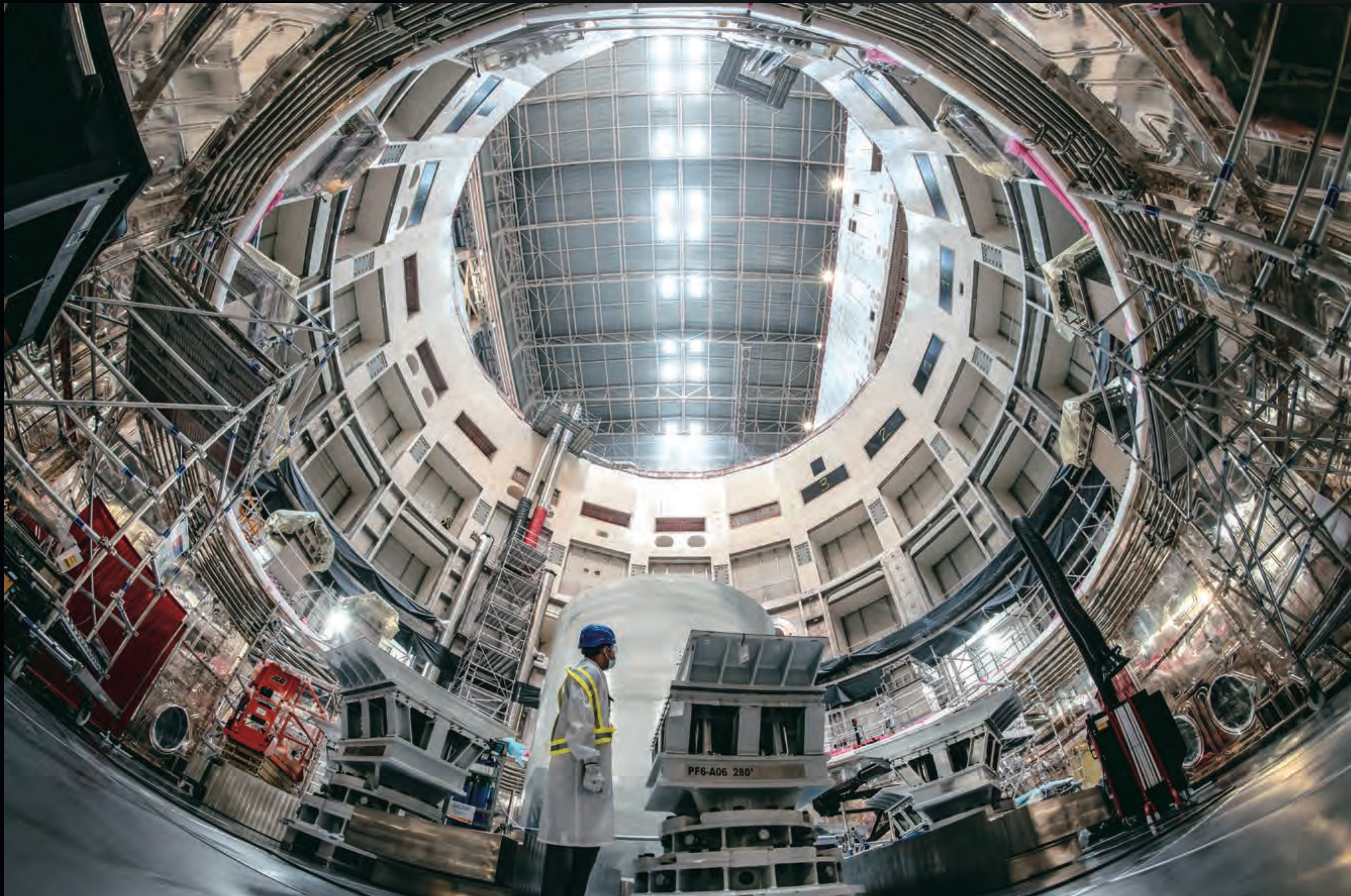
Some of ITER’s most spectacular bespoke tools are in action in the Assembly Hall, where pre-assembly activities are carried out on the largest components of the ITER machine. In this photo, the "upending" tool transfers a 440-tonne vacuum sector from horizontal to vertical.

More than 4.5 kilometres of cable galleries run underneath the ITER platform. In certain places, where the cables bend towards the surface, the impression is that of tentacles belonging to a creature lurking in the depths.

Taken from high above, this fisheye view shows the first vacuum vessel module, comprising components from Korea and Japan, being assembled in one of the twin sector sub-assembly tools.

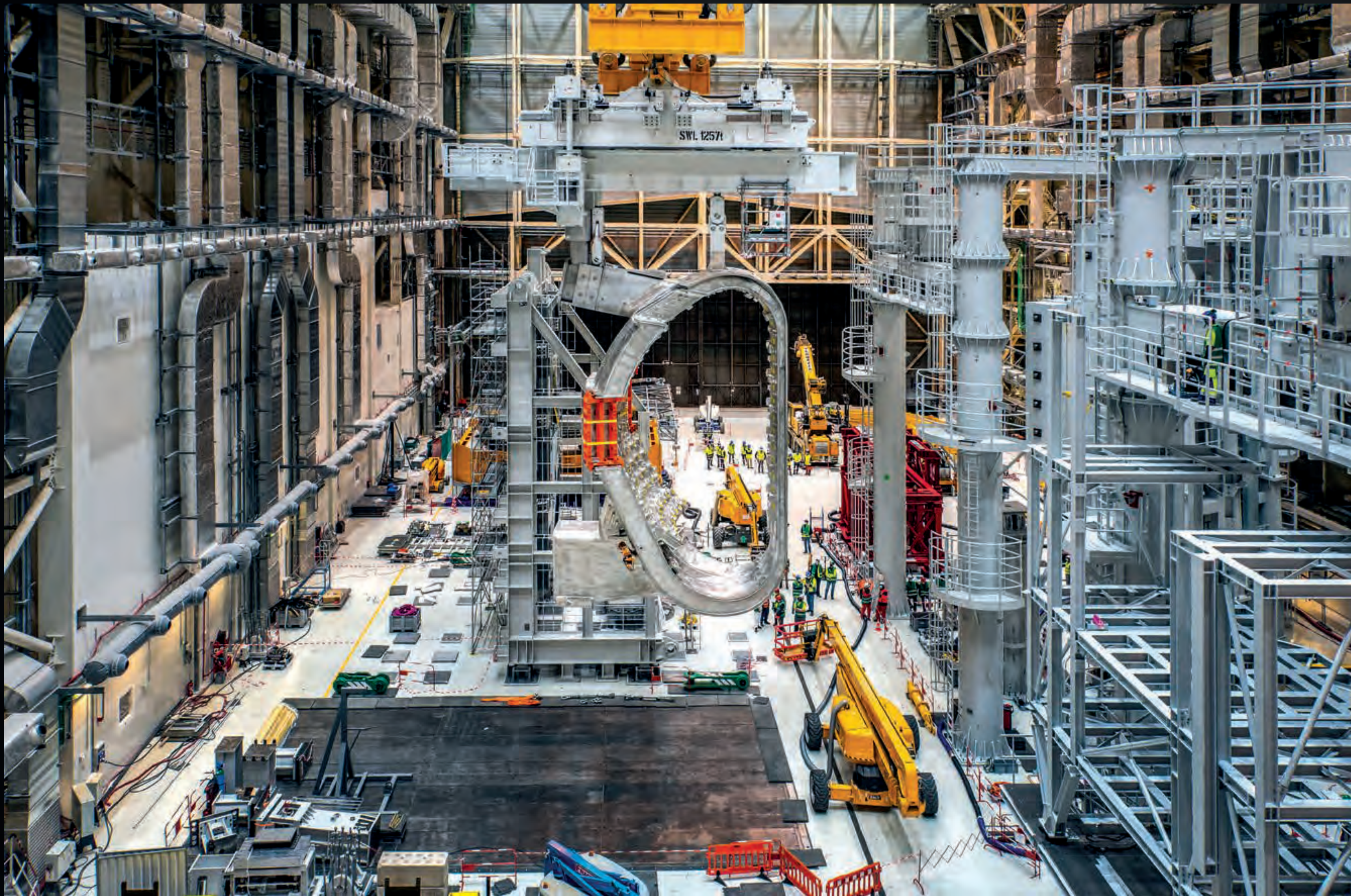
A spectroscopic laboratory has been created in Moscow to support the development of the optical diagnostic systems, which are used to measure temperature and density profiles at the core or the edge of the ITER plasma.

2021



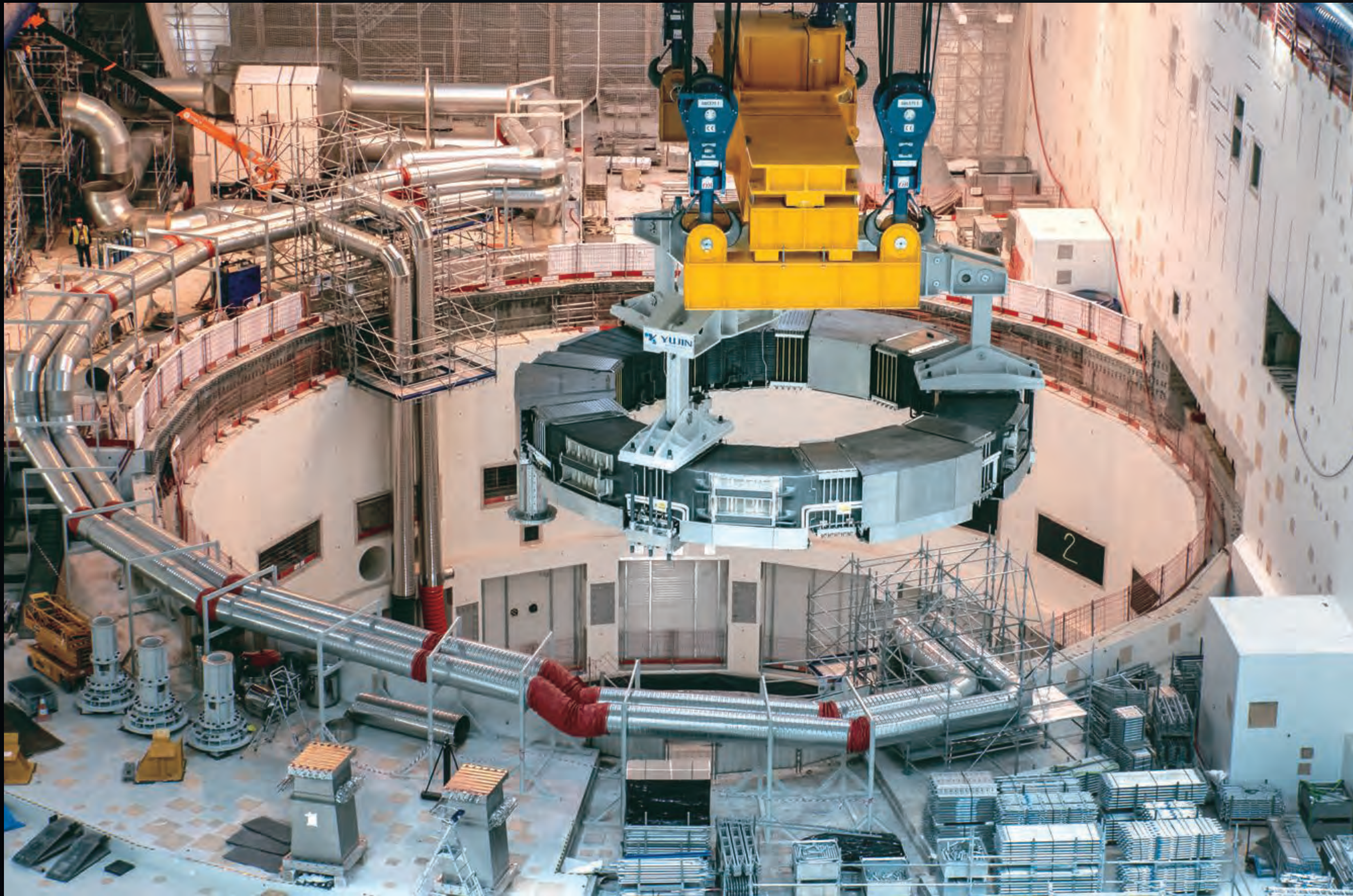
Core machine assembly started in May 2020. The cryostat base and lower cylinder, the lower cryostat thermal shield, and the gravity supports for toroidal field coils have been installed and temporary supports are ready to receive poloidal field coil PF6.

In 2021, the assembly pit is declared "ready" for the first vacuum vessel sector after all captive components (like the magnet feeders pictured here) are installed.



Between the hooks of the overhead crane and the 440-tonne sector module are rigging elements that act as veritable tools, with the capacity to control the load's centre of gravity and pilot the rotation of the component.

2021



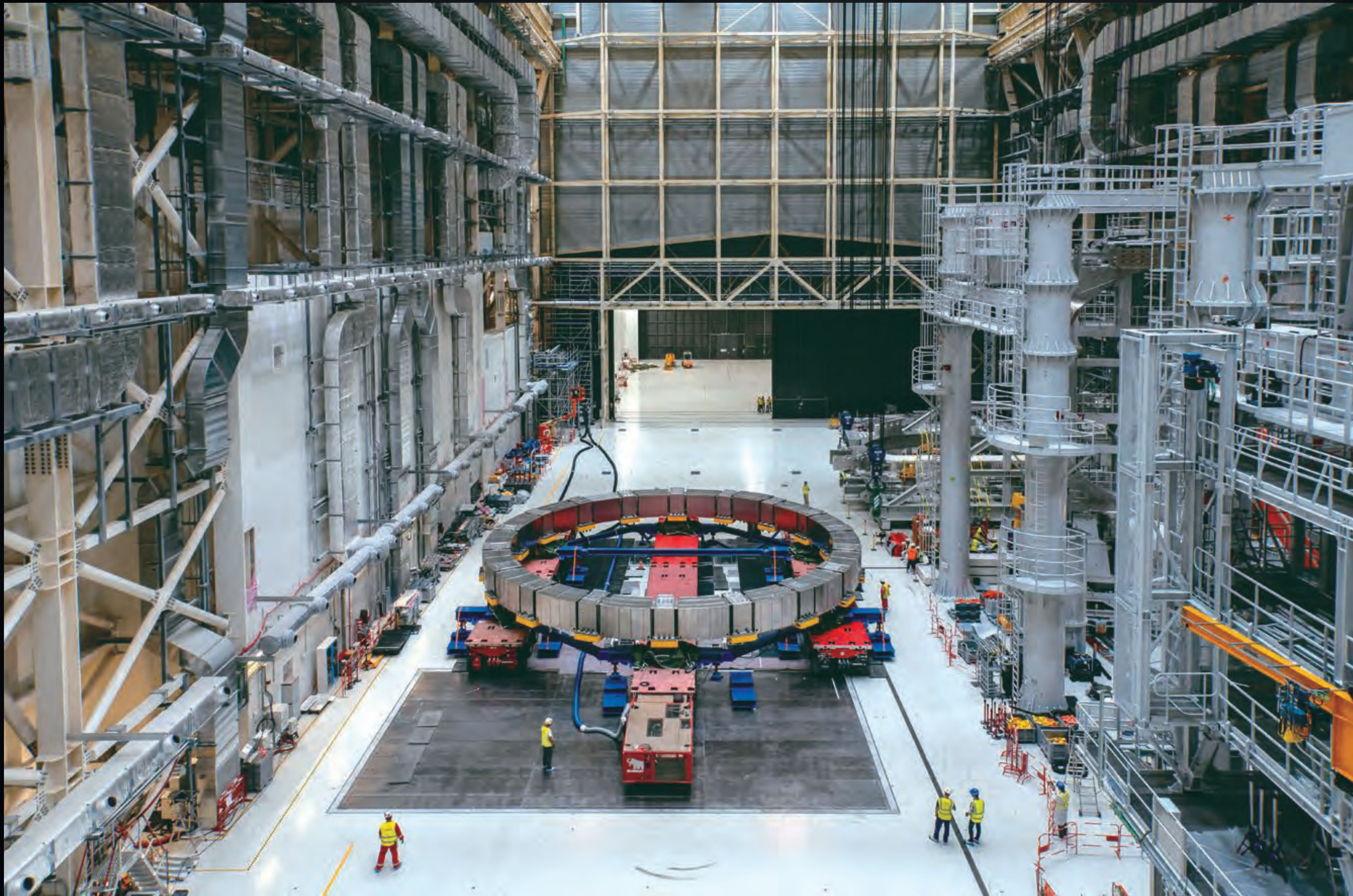
The installation of the first magnet, 330-tonne poloidal field coil PF6, is a major assembly milestone achieved in April.

Put end to end, the electrical cables that crisscross the ITER scientific installation could reach the Peruvian capital Lima from the south of France—a total of 10,000 kilometres. Part of the 66kV underground network is shown here.

2021

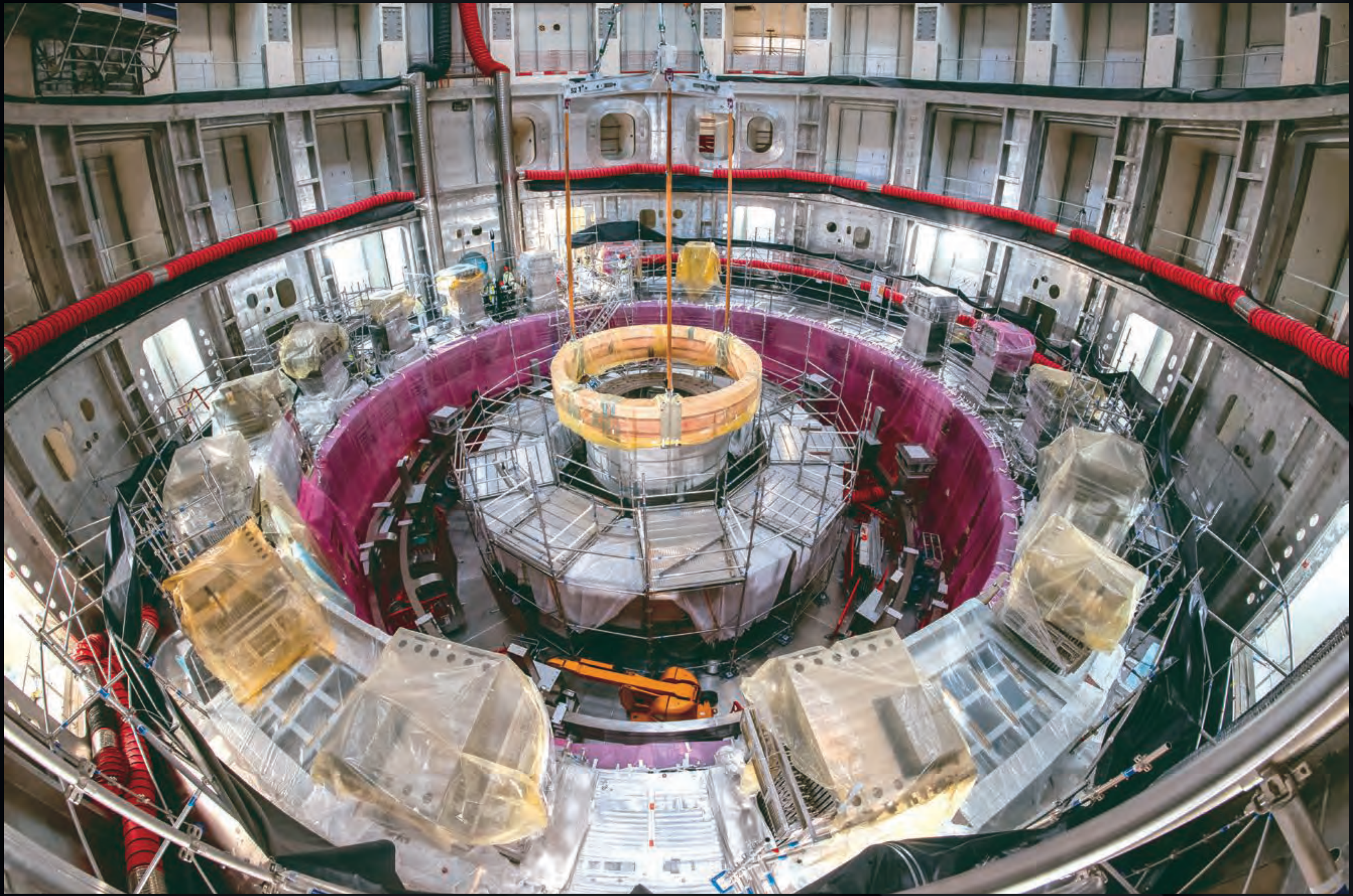
Eighteen small superconducting coils inserted between the major toroidal and poloidal field systems will help correct unwanted field perturbations that can affect plasma stability and confinement. All six bottom correction coils have been installed.

These Monaco Fellows have taken up their positions thanks to funding from a longstanding partnership with the Principality of Monaco. Every two years since 2009, five Fellows have been recruited to work with ITER scientists and engineers on top project priorities.

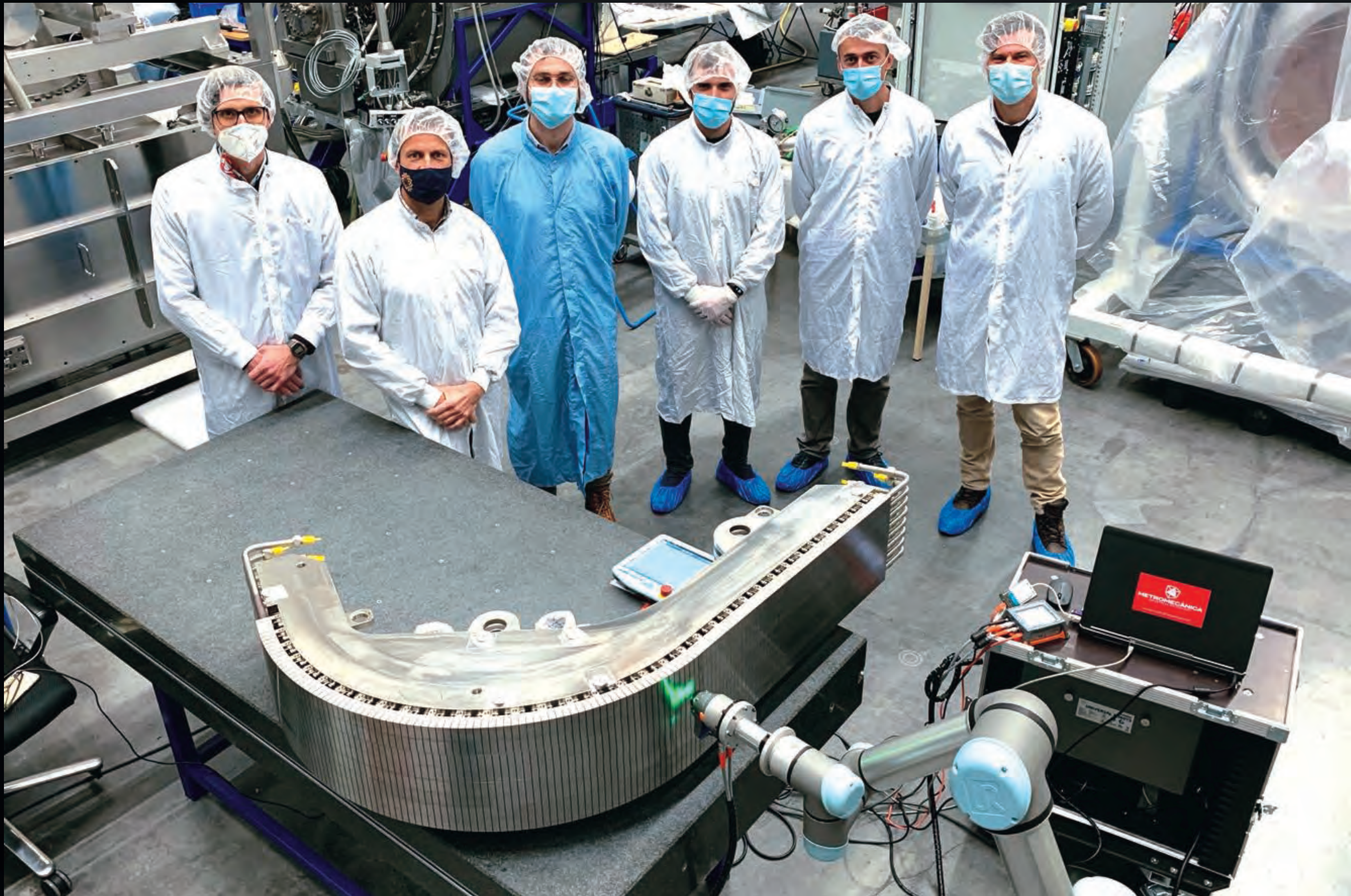


The double doors are closing behind poloidal field coil PF5, which has just been delivered from temporary storage into the Assembly Hall. It will be lifted from its modular transport vehicle and set on temporary supports until its installation in the tokamak pit.

Approximately 1,200 people work directly for the ITER Organization, most based out of ITER Headquarters (foreground). In addition, 2,500 ITER Organization contractors and 1,400 Fusion for Energy staff and contractors work daily on site.



Procured by Europe, pre-compression rings like those in the centre of this image are part of the ITER magnet system. Made of glass fibre/epoxy composite, they will tightly hold the toroidal field coils at top and bottom with a radial force of 7,000 tonnes per coil. Two sets of three are required for operation; pictured is a spare set that was inserted at the bottom of the assembly pit in July.



Representatives of Fusion for Energy, Research Instruments, and Metromecanica observe dimensional tests on a full-scale divertor inner vertical target prototype. The target's surface is made of small monoblocks in tungsten, which can withstand some of the highest heat loads of the ITER machine.

Twin buildings on site are filling up with equipment to convert AC power to DC power for the superconducting magnets. This converter from Korea will is part of equipment that will feed power to the vertical stability coils.

A cryoline spool is lowered into the ITER cryoplant, part of the multi-process piping system that will transport cooling fluids to the Tokamak Building in the background.

Korea delivers a second vacuum vessel sector to ITER in August 2021. Nine sectors in total will form the torus of the ITER tokamak.

iter
china eu india japan korea russia usa

2021

At QST's Naka Fusion Institute, eight gyrotrons are on display. These heating devices produce a high-intensity beam of electromagnetic radiation to heat the plasma as part of the electron cyclotron resonance heating system.

Poloidal field coil PF2 measures 17 metres in diameter and weighs just over 200 tonnes. In December, it was moved to temporary storage—the second of four ring-shaped coils to exit the on-site European manufacturing facility.

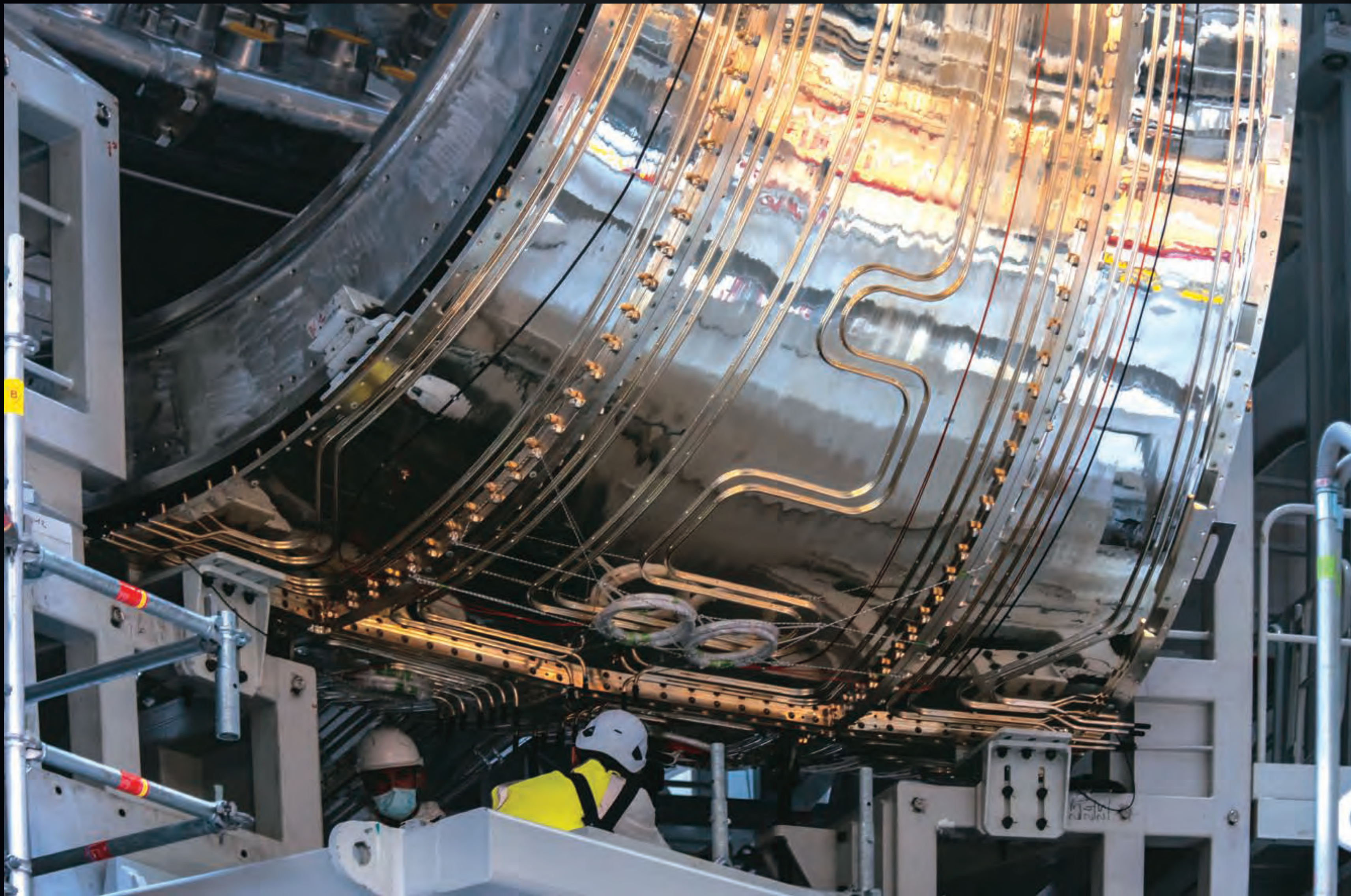
The first major machine components are in place at the bottom of the tokamak pit—the base and lower cylinder of the cryostat, the first two poloidal field coil magnets, and 18 supports for the toroidal field magnets. The first vacuum vessel sector will join them next year.

Prototypes for the low field side reflectometer diagnostic are in development at General Atomics. This diagnostic system will monitor electron density and aid in the assessment of fusion performance.

The Assembly Hall is a busy place, with components entering and exiting in different stages of handling, pre-assembly, lifting and transport. Contractors have learned to share space, tooling and common services in an efficient manner as they execute work packages under the oversight of the ITER Organization.

A high-voltage power supply system is installed in the Radio Frequency Building for the electron cyclotron resonance heating system, one of three auxiliary heating systems on ITER.

ITER Director-General (interim) Eisuke Tada conducts a management walkthrough of the worksite in July.



Once suspended vertically in tooling, a vacuum vessel sector is paired with its thermal shield (visible in this picture) and two toroidal field coils. The result is a "vacuum vessel sector module," ready for transfer into the tokamak pit.

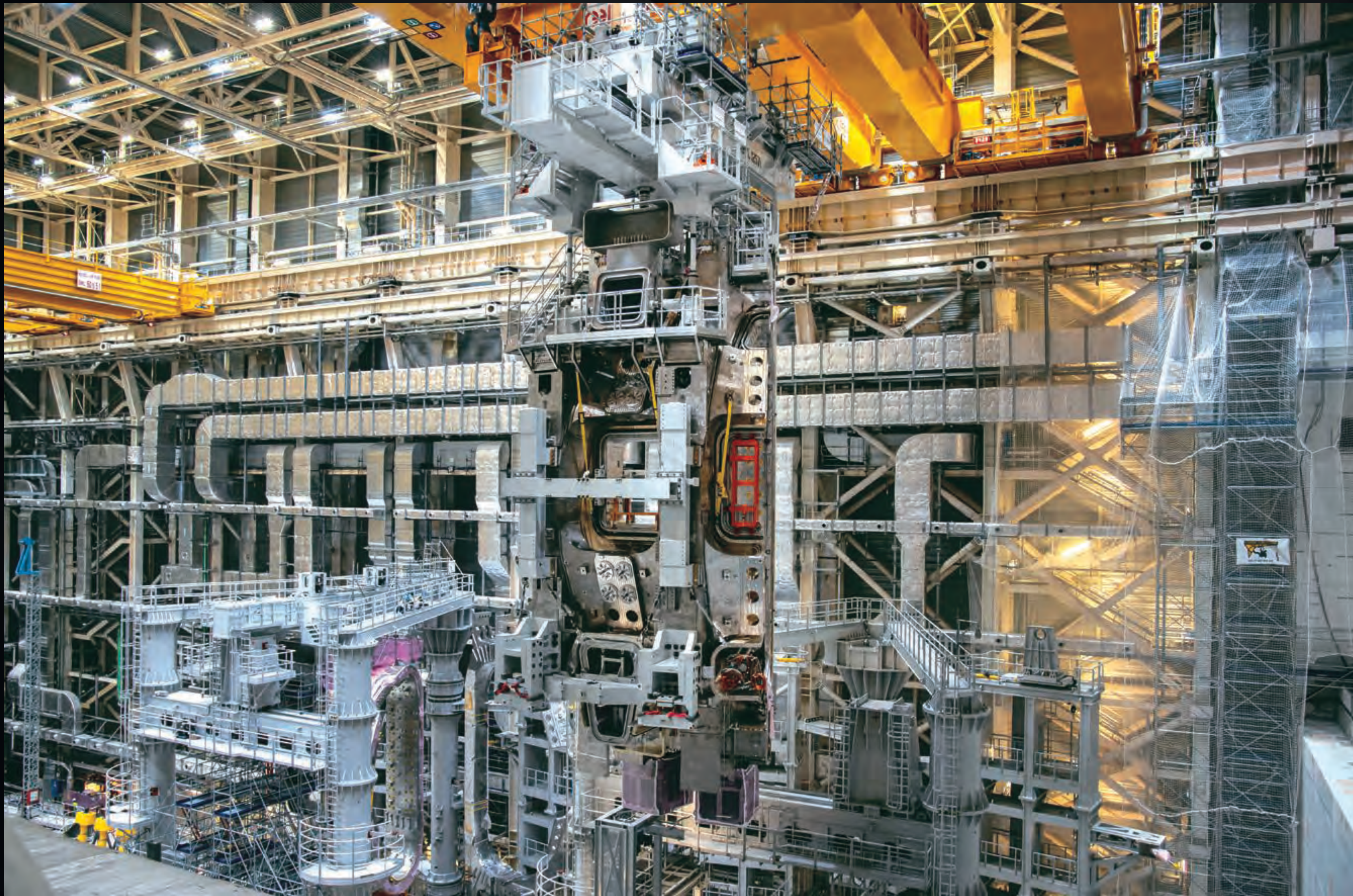
The first of six central solenoid modules is transferred to a staging area in the Assembly Hall. Six modules will be stacked to form the 1,000-tonne central magnet of the ITER machine.

The heat rejection system is the final cooling loop of the ITER installation, ultimately dissipating the heat load generated during operation. The necessary infrastructure is concentrated in a 6,000-square-metre area (background) that comprises hot and cold cooling water basins, powerful pumps, heat exchangers, and an induced-draft cooling tower with ten individual cells.

In the Assembly Hall, work is underway on a second vacuum vessel sub-assembly, with technicians at every level.

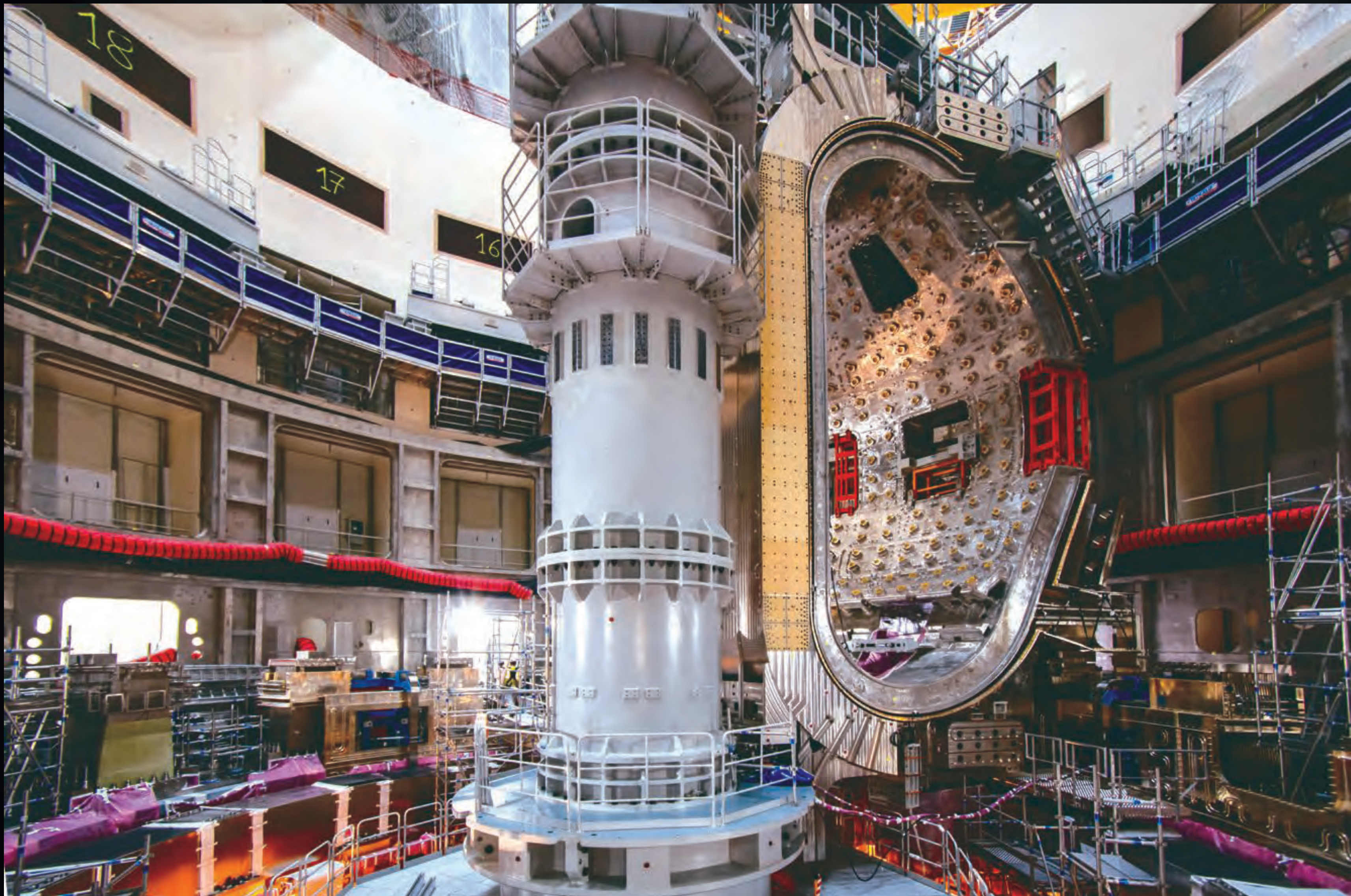
The four sections of the cryostat—base, lower cylinder, upper cylinder and top lid—have been successively assembled and welded in India's Cryostat Workshop. With the top lid finalized (photo), the ITER community can celebrate the completion of a decade-long industrial adventure.

Vacuum vessel sector #6 is raised 50 centimetres and then redocked as part of a rehearsal for the big lift to come, which will bring the sector into the tokamak pit. The operation allows the teams to test rigging, sequences, and coordination.



The first-completed sector module—sector #6, 1,380 tonnes—is lifted out of tooling in the Assembly Hall. It takes two days to extract the module, transport it over the wall to the tokamak pit, and position it with sub-millimetric precision on supports.

The first sector module—representing one-ninth of the torus-shaped vacuum vessel—is installed in the tokamak pit. Welded together, eight other similar assemblies will form the complete chamber and surrounding toroidal field coil superstructure.



In the last phase of the lift and installation, the sector module is suspended only 50 centimetres above its supports in the assembly pit, as the assembly team carries out final metrology. Team coordination, the overhead crane's lifting capacity, and rigging maneuverability were all tested successfully during this first-of-a-kind operation.

2022

Each vacuum vessel sector is assembled from four smaller segments. In this photo of Europe's sector 4, we can see two segments coming together.

Deep in the basement of the Tokamak Building, trained specialists are assembling the first superconducting feeder joints to connect high-current busbars. This highly technical operation must be repeated approximately 300 times.

2022

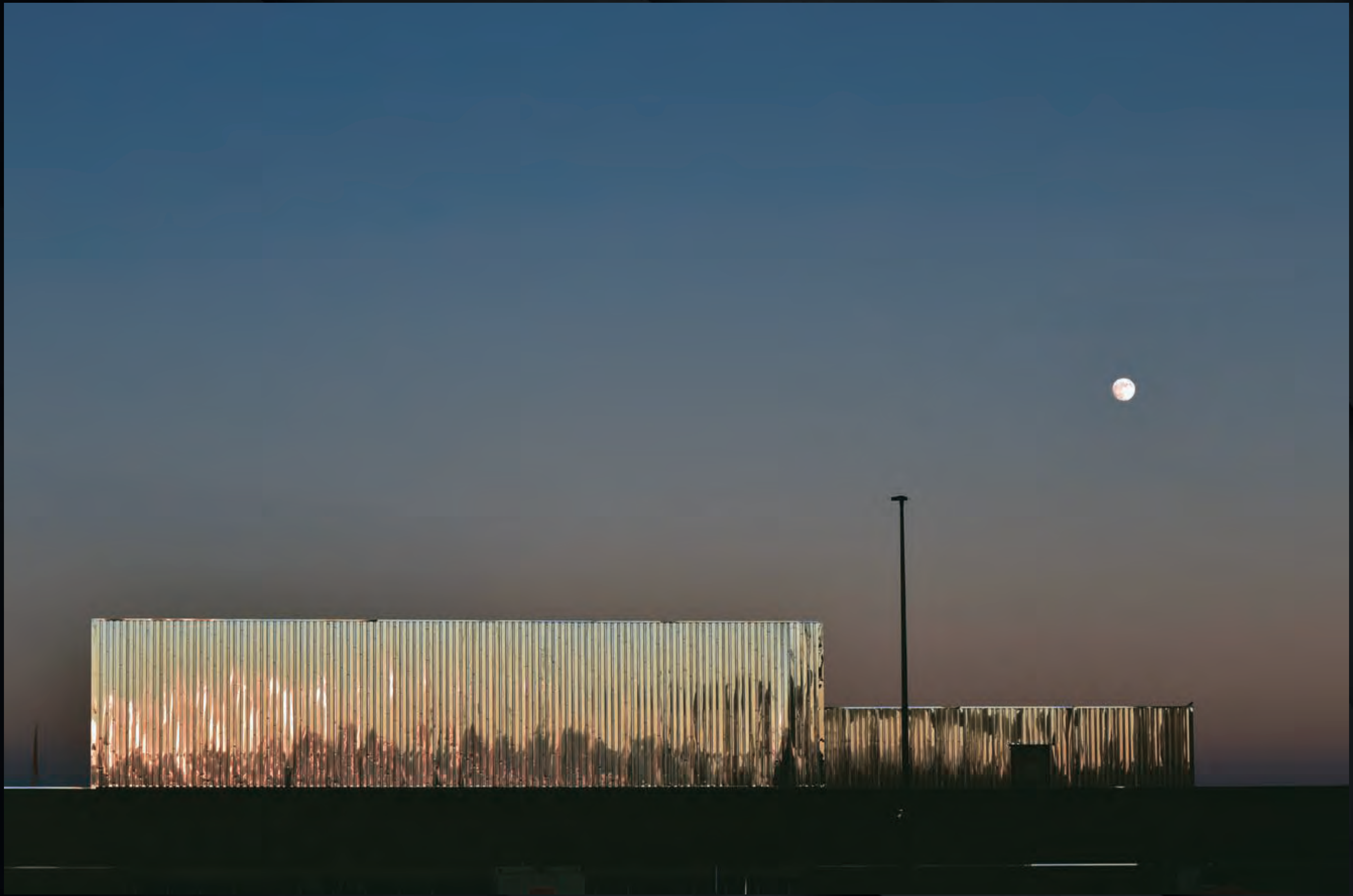
Cryolines travel back and forth between the cryoplant, where cooling fluids are produced, and the Tokamak Building. One section of cryoline can host up to six or seven "process pipes," each devoted to a specific fluid, flow direction or function.

ITER's new Director-General, Pietro Barabaschi (second from right), greets staff for the first time since his appointment. With him on stage are the heads of six Domestic Agencies (China is not represented) and his Deputy Eisuke Tada.

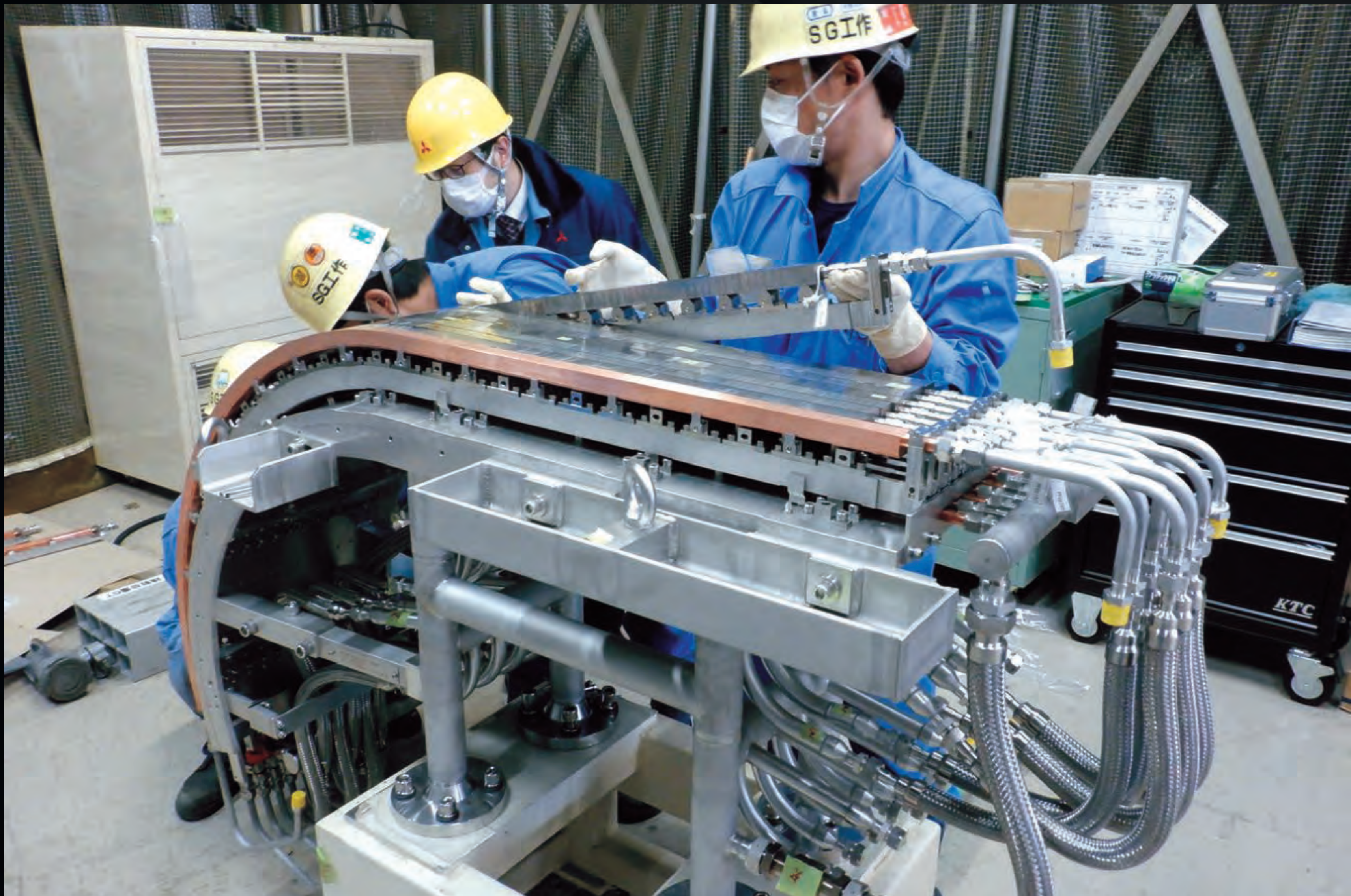
The project announces in November that vacuum vessel assembly must be halted as two key components—the thermal shield and vacuum vessel sectors—require repair. Outside experts are consulted in the definition of repair and remediation strategies.

After a ceremonial launch at the Sredne Nevsky shipyard in Saint Petersburg, ITER's smallest ring-shaped magnet—poloidal field coil PF1—has been loaded on a transport vessel for shipment to France.

The bulk of infrastructure needed for the start of research operations is finished, but here and there on the worksite smaller buildings are still in construction.
Pictured: teams work on the foundations of two electrical distribution buildings.



The moon rises over the ITER Control Building, a three-story, 3,500-square-metre facility that will be the nerve centre of ITER experimentation.



Japan is in the last phase of qualifying the divertor outer target, which will be exposed to the highest heat load of the ITER machine (on the order of 20 MW/m²).
Here, plasma-facing elements are mounted on a test assembly for high-heat-flux testing.

Six independent magnet modules will be stacked to form the central solenoid. The first one, whose helium input pipes and electrical connections are seen here from below, has been positioned on a dedicated assembly platform in the Assembly Hall.

The top ring coil of the ITER machine, PF1, arrives on site four months after leaving Russia. It is the smallest of the ITER machine's six poloidal field coils, with a diameter of nine metres.

Hosted in two buildings, the power supply infrastructure for the ITER neutral beam injection system will accommodate an array of transformers, generators, rectifiers, inverters and other exotic electrical devices designed to feed 1 MeV ultra-high voltage to the neutral beam injectors in the Tokamak Building.

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china eu india japan korea russia usa

From the ITER Control Building, going up on the north corner of the ITER platform, approximately 80 operators, engineers and researchers will conduct experiments on the ITER tokamak or manage the routine 24-hour operation and control of the machine and plant.

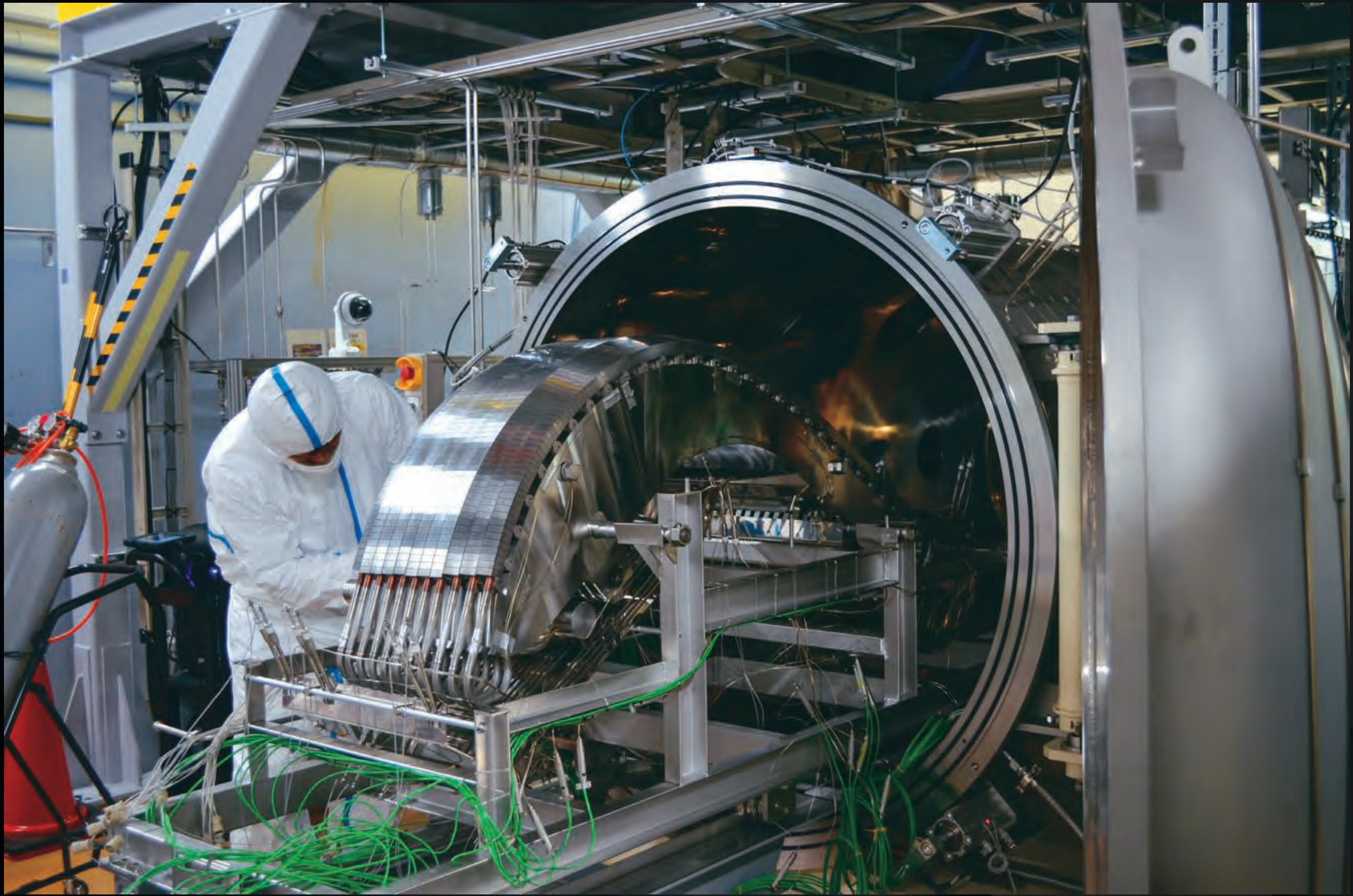
The virtual reality room is used by technical responsible officers and configuration managers for design and engineering activities. The "immersive" experience helps to identify and resolve integration challenges.

With the staff pool growing, the ITER Organization now organizes Open Doors Day events just for families. These popular events allow project collaborators to share their work environment with spouses, children, parents and friends.

A powerful telephoto lens captures the full moon over the ITER worksite from a distance of 4.5 kilometres.

On May 1, 2024, Taro Matsumoto was appointed as the new Head of the ITER Japan Domestic Agency. The entire domestic agency team gathered for a group photo to commemorate the leadership transition, symbolizing their unity and commitment to advancing fusion energy development.

Prototype of the Divertor Outer Vertical Target (OVT) manufactured by Mitsubishi Heavy Industries was installed to the vacuum vessel of the Hot Helium Leak Test facility i n JADA Naka-site. Stringent leak tightness of OVT prototype at room temperature and 250 oC was demonstrated.



This divertor outer vertical target prototype manufactured by Mitsubishi Heavy Industries in Japan prepares to enter hot helium leak testing.
The validation phase of this critical plasma-facing component has almost concluded; series manufacturing comes next.

ITER Divertor Outer Vertical Target (OVT) prototype manufactured by Mitsubishi Heavy Industries was completed in JADA Naka-site.

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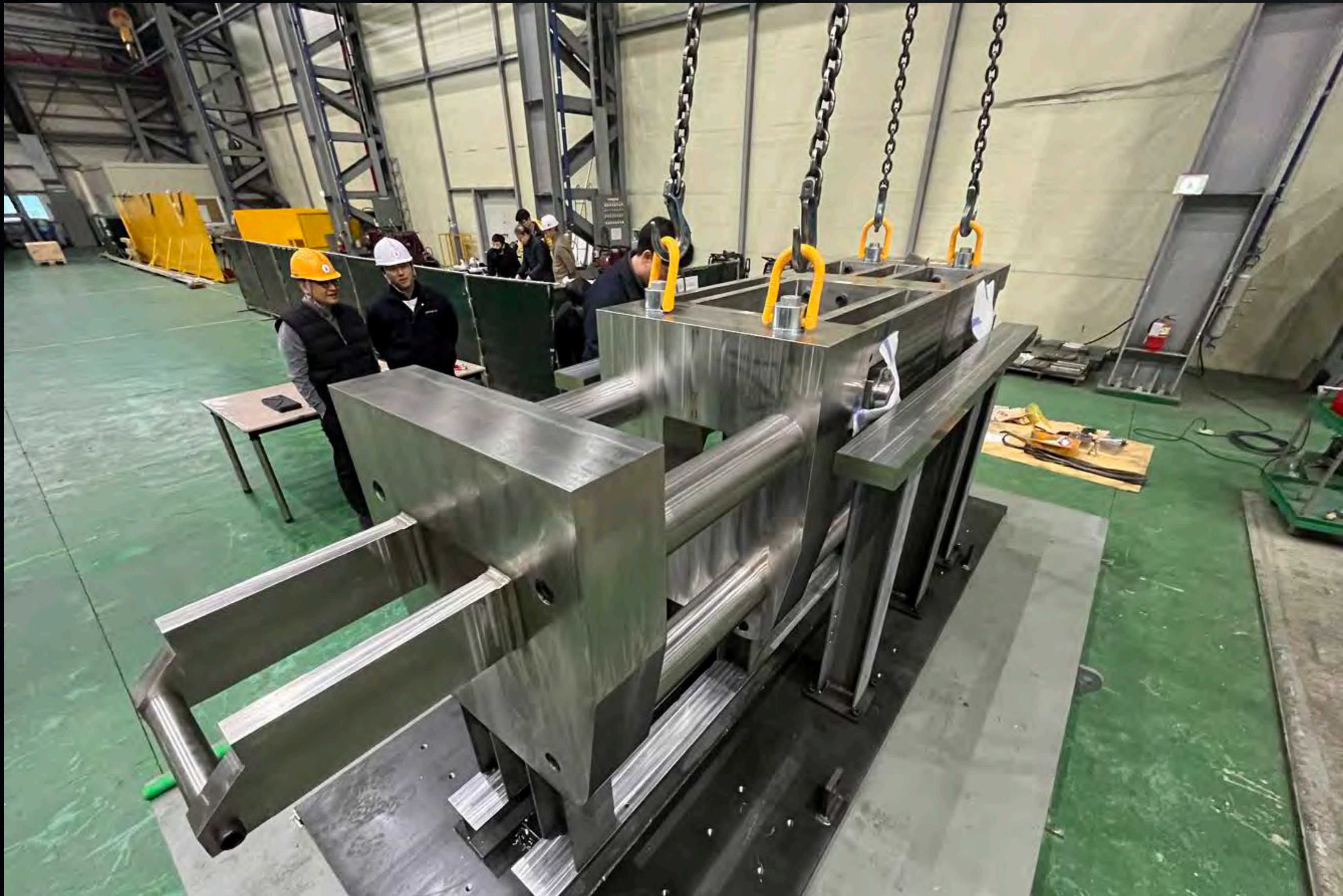
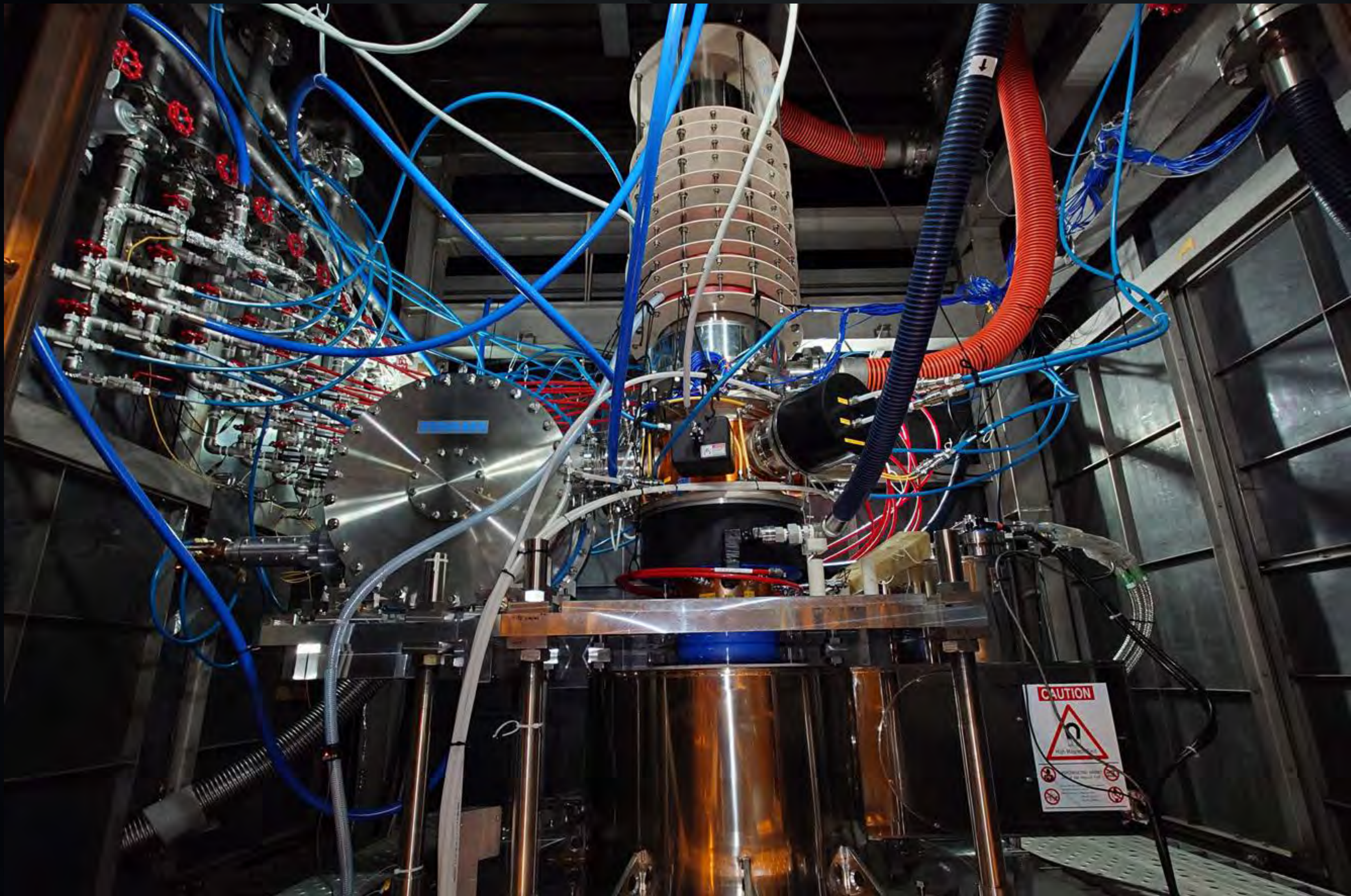
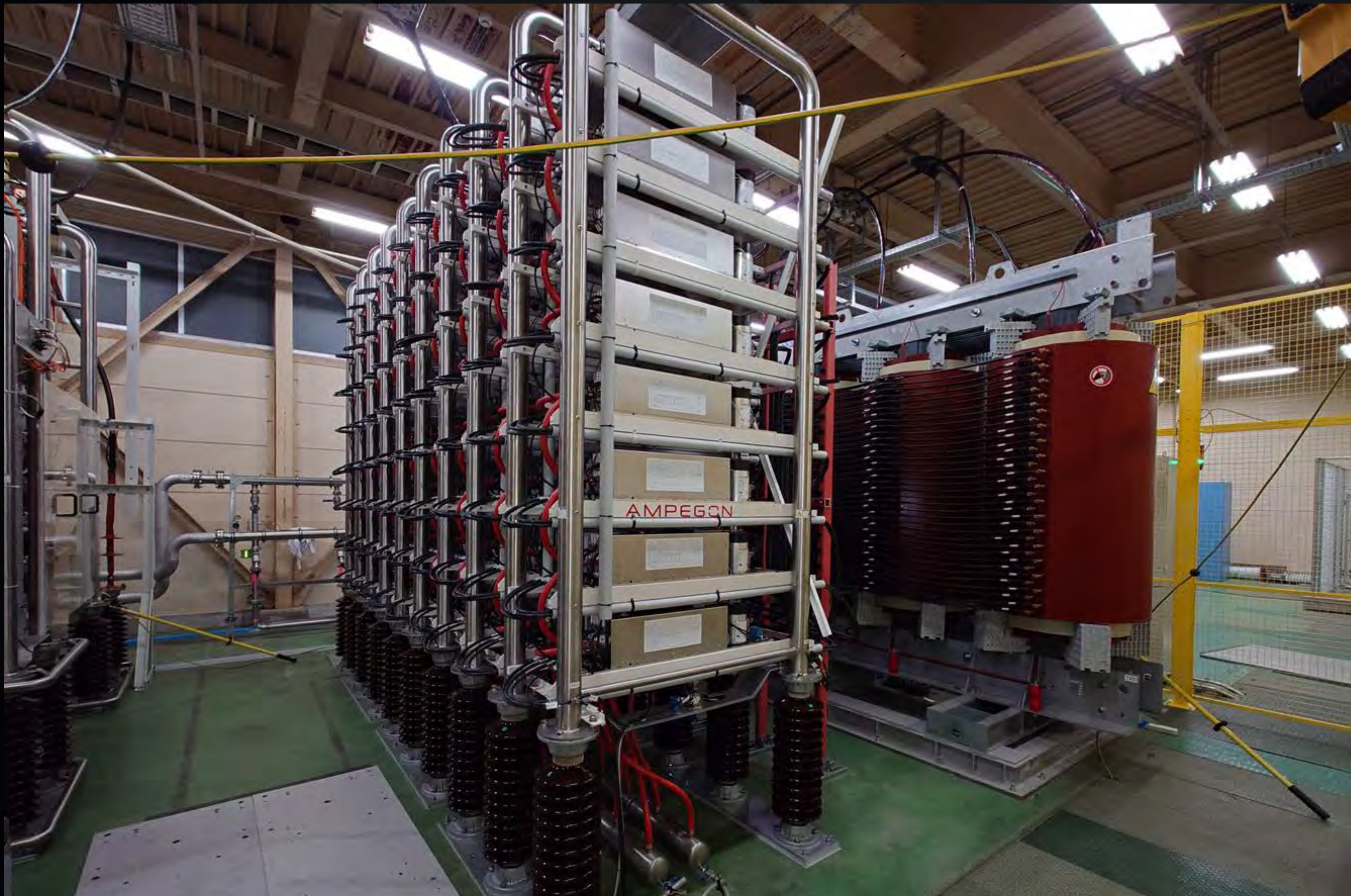
2023



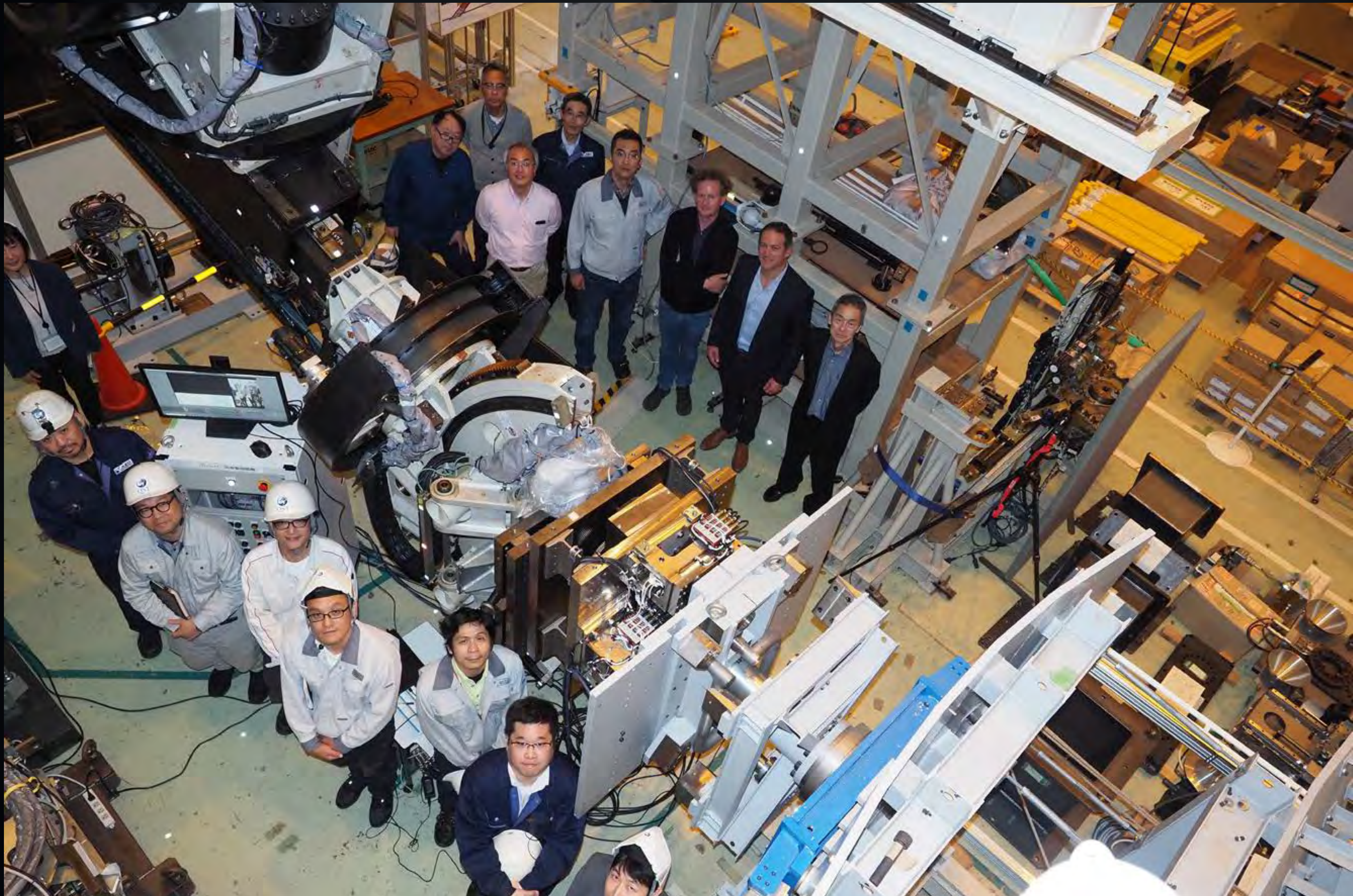
JADA and KODA cooperated on mock-up manufacturing. The JADA diagnostic rack design was selected as a common design for the ITER lower port integrations.
The final functional test before the design phase ends will be implemented in 2025.



FAT of last gyrotron (one of 8 JADA procured gyrotron) has finished at Naka Institute in QST. Twenty successive shots with 300sec. pulse width / 1MW output power / 50% electrical efficiency is achieved without any failure. It is one of the FAT test items for demonstration of the high reliability.



Modern PSM high power supply for gyrotron operation was introduced in QST for imitate the ITER gyrotron power supply. The stable beam current operation was confirmed with JADA gyrotron. The operation parameter by using PSM power supply is learned for ITER Sight Acceptance Test (SAT).



FW handling tests are on-going using the full-scale prototype of the Vehicle Manipulator of the Blanket Remote Handling System, which was designed and manufactured by Toshiba Energy Systems & Solutions. JADA performed the FW installation/removal demonstration during the visit of IO members to Naka on November 8th, 2023.

Captions To develop composite cable feeding control technology and cable guide mechanism for cable handling equipment, a mock-up test rig was fabricated and completed on March 31, 2023. Test is currently ongoing to reflect the results to the design.

The ITER Council is hearing plans for a new ITER Baseline. The project's scope, schedule, cost and risk plans need updating to reflect first-of-a-kind technical issues, delays in the assembly of the machine, and challenges in the context of the ITER safety demonstration.

In order to repair the dimensional non-conformities in the vacuum vessel sectors and corrosion-induced cracks in the cooling pipes of the thermal shield panels, the decision is made to extract sector module #6 from the assembly pit for disassembly and repair. Vacuum vessel assembly activities must be temporarily halted.

The same team responsible for the lift and installation of the 1,350-tonne sector module #6 in May 2022 is responsible for its extraction, a complex and delicate operation.

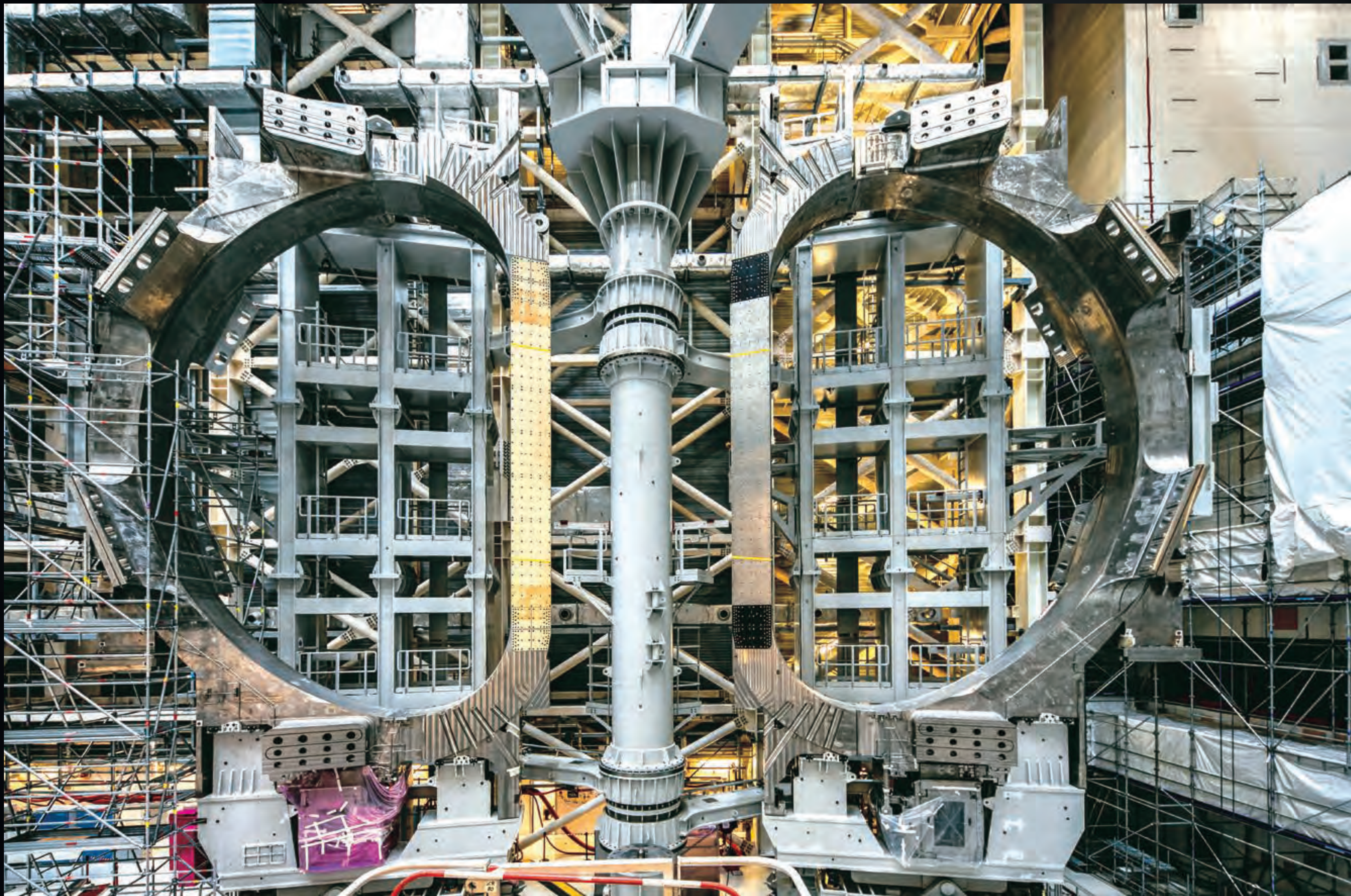
From detaching the module from its moorings in the assembly pit to lifting and transporting it to the sub-assembly tool, more than one hundred different steps were defined, validated and integrated into the lift procedure.

Cooling fluids and DC current leaving their production sites will be transported across elevated steel structures referred to as "bridges" to reach the Tokamak Building. Each one will support hundreds of tonnes of equipment.

Safety days are organized annually to remind all project actors—whether they spend their day in an office or in the Tokamak Complex—
that a commitment to workplace safety is essential. Through stands, displays, hands-on activities and games, exhibitors raise awareness on this all-important issue.

Installation activities are progressing full speed in the Tokamak Complex. Here, the first of the five auxiliary cold boxes required to distribute cooling fluids to different "clients" inside the machine is transferred into the Tokamak Building.

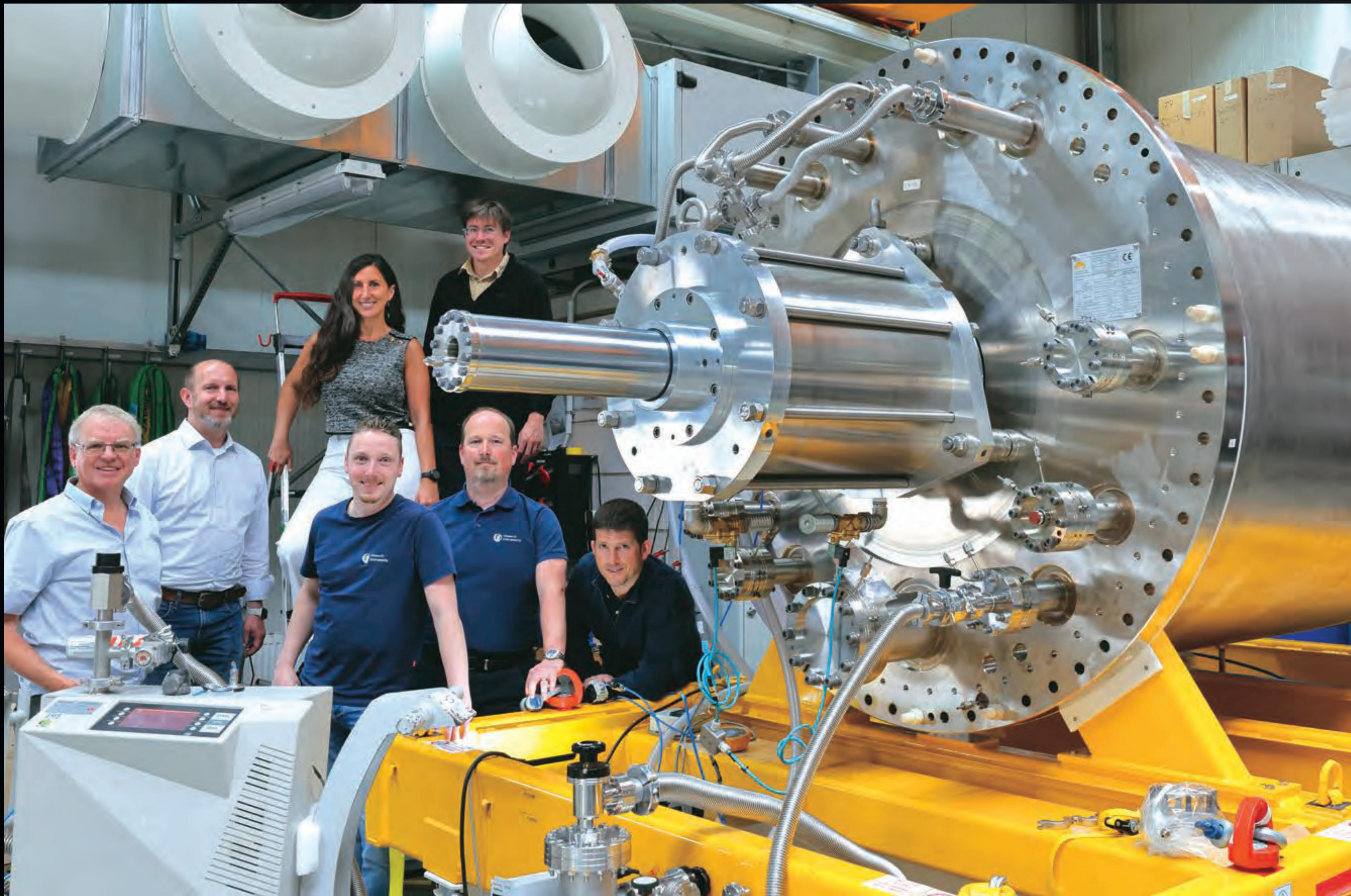
One after the other, each of the scientific buildings on the platform is given the ITER signature finish (mirrorlike stainless steel alternating with dark greylacquered metal) to compose a striking architectural imprint on the Provençal landscape.



Displacement and dismantling operations have created a unique opportunity to photograph toroidal field coils in the wings of the tool without obstacle. Pictured are TF9 from Europe and TF8 from Japan.

Fusion for Energy (the European Domestic Agency) and contractors celebrate the completion of Tritium Building civil construction. In all, works spanned 14 years.

Toroidal field coil procurement ends with this delivery of this magnet—TF18 from Europe. This concludes one of ITER's lengthiest and most complex industrial efforts. Nineteen coils in all were procured and delivered by Europe and Japan.



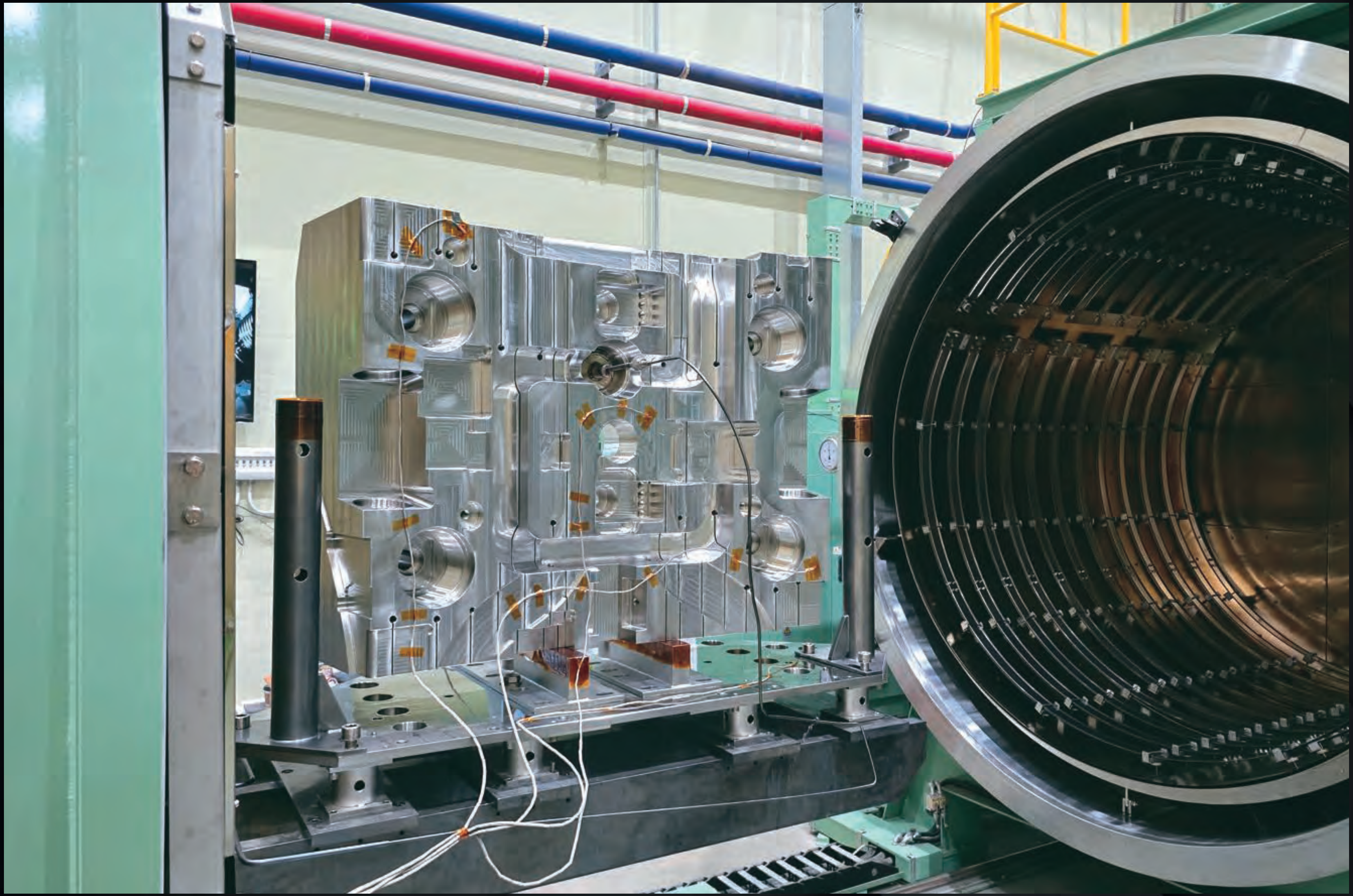
The first cryopump has passed factory acceptance tests at Research Instruments, Germany. ITER will rely on six torus cryopumps to maintain ultra-high vacuum inside the ITER vacuum vessel during operation and to create low density—about one million times lower than the density of air.

In early 2024, ITER scientists team up with colleagues at the EAST tokamak in Hefei, China, for a campaign of joint physics experiments designed to address specific ITER questions on the reliability and operability of tungsten as a plasma-facing material. In a modification decided by the ITER Organization last year, tungsten will replace beryllium as the first-wall armour material of the ITER blanket.

The new ITER plans for construction and operation must be reflected in detail in its scientific blueprint—the ITER Research Plan. In February ITER Organization staff and Member experts meet to review and optimize the Plan for submission to the ITER Council Science and Technology Advisory Committee (STAC).

A repair program is underway to replace all thermal shield cooling pipes after analysis showed instances of stress corrosion cracking. Once repaired or re-manufactured, vacuum vessel thermal shield panels like this one will be reassembled with vacuum vessel sectors and toroidal field coils to form the modules that constitute the doughnut-shaped plasma chamber.

In Korea and in China, where blanket shield block procurement is underway, approximately 55 percent of fabrication is now complete. In this photo, 3-tonne shield blocks are inspected during a progress meeting at Dongfang Heavy Machinery, China.



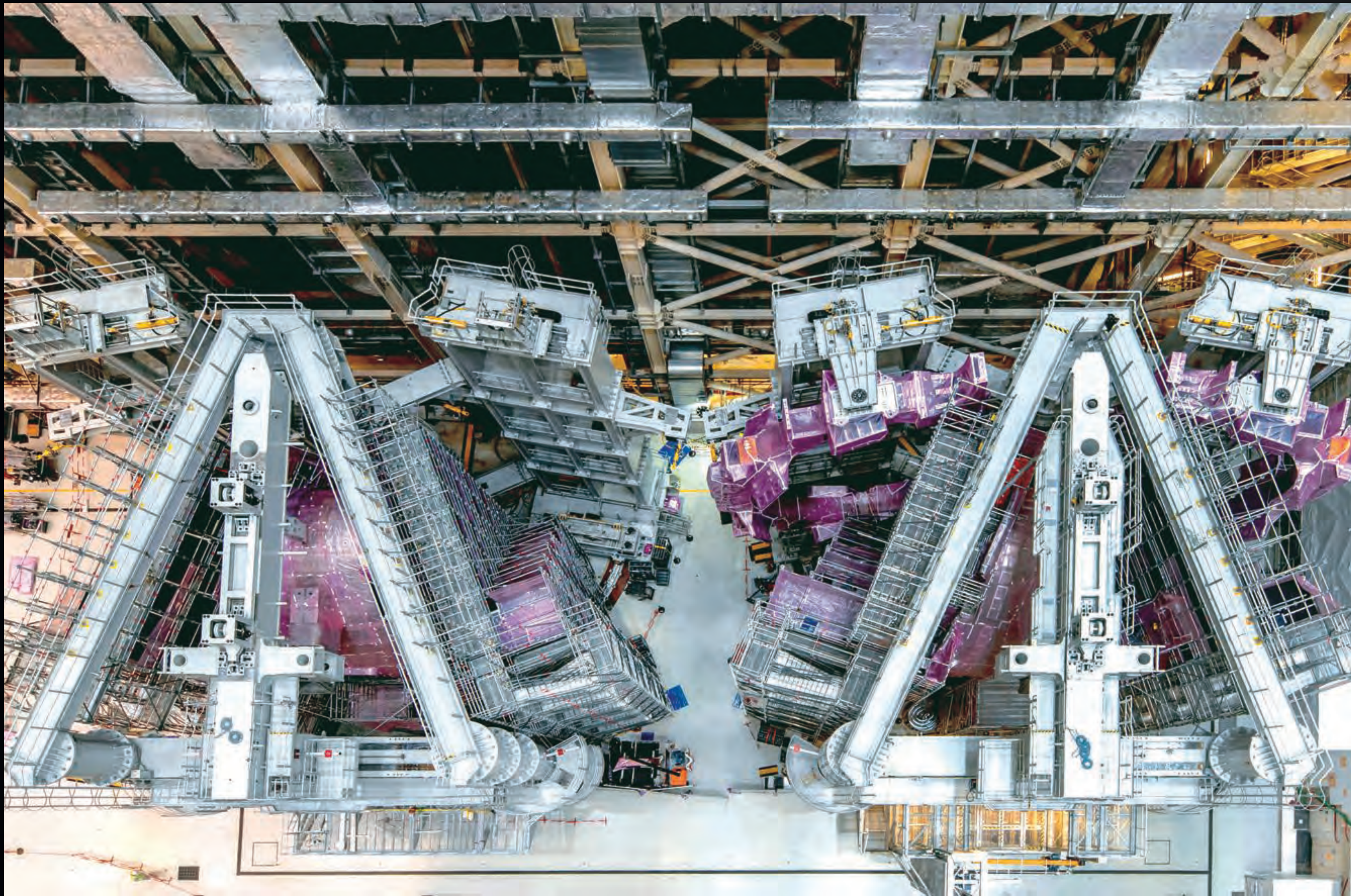
Thick steel blanket shield blocks covering the inner surface of the ITER vacuum vessel will absorb most of the radiative and particle heat fluxes from the hot plasma and stop or slow down the neutrons that result from the fusion reactions. Its complex shape—full of gullies, channels, gaps, and cutouts—has been challenging to manufacture. Here, a shield block is prepared for hot helium leak testing at Vitzrotech, Korea.

The last of six poloidal field coils required by ITER leaves Europe's manufacturing facility in April. Between 2017 and 2024, Europe produced four of these critical ring-shaped magnets—PF5, PF2, PF4 and PF3 (photo). Two other coils were manufactured in Russia (PF1) and China (PF6) and shipped to ITER.

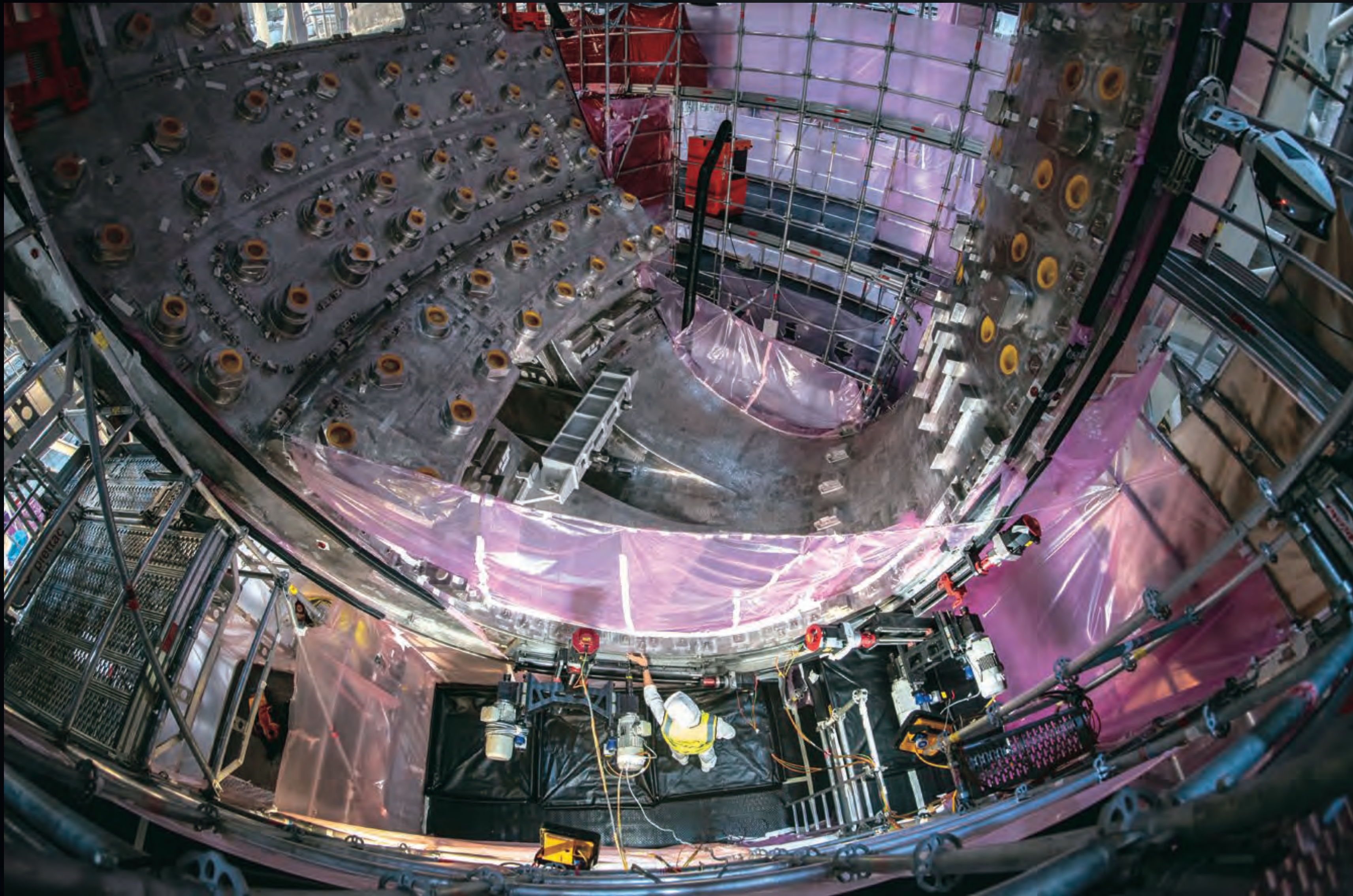
After a two-year shutdown for upgrades, the SPIDER testbed at the ITER Neutral Beam Test Facility in Padua, Italy, is preparing for commissioning and operation.
SPIDER is a full-size negative ion source that is designed to demonstrate all the critical aspects of the ion sources for ITER's heating and diagnostic neutral beam injectors.

A campaign is underway to repair the dimensional non-conformities in the outer shell field joints of three vacuum vessel sectors. Pictured, scaffolding surrounds sector #7 as contractors work at four different levels to re-work the bevel joints by either building up missing material or shaving off excess material through machining.

The central solenoid "stack" is taking shape in the Assembly Hall. In April, the third module is lifted with the aid of a bespoke lift tool and positioned over the two modules already in place. Six modules in all will create the 18-metre-tall central solenoid magnet.



Seen from the Assembly Hall rafters: repairs are carried out simultaneously on vacuum vessel sectors #7 and #6. Work on sector #7 (left) is nearly completed, signifying that the sub-assembly process can be restarted soon.



The geometry of the outer shell field joints—where sectors are to be welded together—must be restored to nominal so that the access and operation of the bespoke automated welding tools in the tokamak pit is not compromised. Two sectors are being repaired in vertical tooling; a third, sector #8, will be repaired in a horizontal position.

Vacuum vessel repair is being carried out at ITER by the SIMANN consortium (SIMIC S.p.A. and Ansaldo Nucleare). Repairs only began after the group had qualified its design solution and tools with mock-ups.

The ITER construction site in June 2024. Most of the technical infrastructure is now in place.

The sharing of knowledge and experience has long characterized fusion research. As the fusion landscape is transformed by an ever-growing number of startup firms, ITER hosts a Private Sector Fusion Workshop in May that asks private initiatives: "How can ITER help?"

The fusion tradition continues, as the ITER Organization, the Domestic Agencies, and fusion startups pledge to work as part of a global fusion ecosystem to accelerate commercialization.

Close to two years have passed since vacuum vessel assembly was halted due to defects identified in the tokamak vacuum vessel sectors and thermal shield. In September 2024, sector module assembly restarts with sector #7.

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